ENDEAVOUR

Volume IX Number 34

APRIL 1950

The drawing on the cover is of the bark Endeavour, *which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in* 1768 *to chart the South Pacific Ocean and observe the transit of Venus*

CONTENTS

Editorial:
The Accessibility of Knowledge 53

621.039.4:539.185
Nuclear Reactors in Scientific Experiments 55
SIR JOHN COCKCROFT, C.B.E., M.A., Ph.D., Hon. LL.D., F.R.S.

681.11
The Clocks of Christiaan Huygens 64
C. A. CROMMELIN

553.99
Amber Inclusions 70
GEORG KIRCHNER

53 (= 1.394)
The Arabic Achievement in Physics 76
H. J. J. WINTER, M.Sc., Ph.D., A.Inst.P., F.R. Asiatic S.

575.23:576.851.214.095.18
Heredity in Pneumococci 80
H. EPHRUSSI-TAYLOR, M.A. Ph.D.

636.2.081
Polled Cattle 85
JOHN HAMMOND, C.B.E., M.A., D.Sc., F.R.S.

550.341
Earthquakes 91
ERNEST TILLOTSON, M.Sc., F.G.S., F.R.A.S.

541.124
The Reactivity of Free Radicals in Solution 98
H. W. MELVILLE, Ph.D., D.Sc., F.R.S., F.R.I.C.

049.3
Book Reviews 102

Some Books Received 106

Notes on Contributors *cover iii*

ENDEAVOUR is published in English, French, Spanish, German, and Italian editions

PRICE FIVE SHILLINGS

ENDEAVOUR

A quarterly review designed to record the progress
of the sciences in the service of mankind

VOLUME IX APRIL 1950 NUMBER 34

The accessibility of knowledge

The first task of a scientist entering a field of research is to master the facts already discovered by earlier workers and then to keep abreast of the discoveries of his contemporaries pursuing the same line. In theory, this process is very simple; in practice, the barriers between the research worker and the facts he needs are often so formidable as seriously to impede the progress of science. In many fields, the accumulation of earlier work and the output of new publications are so great that research in the laboratory is outweighed by that in the library. Even the most conscientious reader frequently finds that he has missed papers which would have filled essential gaps in his knowledge, and awareness of which would have saved weeks or months of laboratory work. The boundaries of the main subdivisions of science either have become blurred or have disappeared altogether, and, as a consequence, there has come into existence a flood of highly specialized new journals. Among so many, it is easy to overlook specific contributions, even those of significance. Consider, for instance, the comparatively new but already important field of antibiotics. Articles on this subject, or articles in some way relevant, may be found not only in journals primarily devoted to it but in other publications, such as those dealing with general science, clinical medicine, surgery, pathology, biochemistry, chemistry, agricultural science, phytopathology, pharmacology, chemical engineering, mycology, bacteriology, nutrition, chemical analysis, and statistics.

There is the further problem of insuring that every research worker knows of developments in branches of science other than his own. In this age of specialization the importance of such access is too often under-estimated, despite the countless examples of problems in one field of science being solved by the application of methods developed in another. For example, polythene, discovered during investigations of chemical reactions at very high pressures, became a decisive factor in the development of radar, and dyestuffs developed by organic chemists have proved of inestimable value to biologists in differentiating tissues and other structures under the microscope, and as sterilizing agents or disinfectants. The task of reporting progress in all branches of science in a form intelligible to scientists as a whole falls upon the scientific reviews.

The fact that science is in danger of suffering from its own weight is apparent to many, but it is not yet so widely recognized as its seriousness demands, although in recent years it has been the subject of very wide discussion. To state the problem is, of course, far easier than to solve it, and it is clear that so far no complete solution has been found.

Certain useful steps have, however, been taken to ease the burden on the research worker. Most notable is the publication of journals of abstracts, the helpfulness of which is too obvious to need emphasis; yet journals of abstracts have inherent disadvantages which make it impossible for them to give the ordinary research worker a complete guide to existing knowledge in his own particular field. The brevity of abstracts inevitably means that they often omit all mention of information contained in the paper except that which is immediately relevant to the main issue. Moreover, abstracts must necessarily appear some time after the original publication, and therefore still longer after the original work was done. Even the most diligent use of abstracts will, as a rule, give no information about work done less than a year previously. Furthermore, in classifying abstracts, it is for administrative reasons necessary to follow the main stream of scientific progress, whereas many individual research workers today are trying to make their way across the current. Take, for

example, chromatography, which has now proved of fundamental importance in almost every branch of chemistry. To follow the course of developments in chromatography itself by studying chemical abstracts is an extremely difficult task, for references to it may be found among papers relating to almost every branch of chemistry. Moreover, if the use of chromatography was merely a means to an end the abstract may not even mention that it was used.

Another way in which the burden on the research worker is being eased, and one which will certainly soon be more highly developed than it is at present, is by the growth of a class of professional literature-searchers, either free-lance or attached to science libraries, who are prepared to summarize, as far as possible, all available literature on any particular subject. Such services are most valuable for many purposes, but a disadvantage is that the professional literature-searcher can never approach his task in quite the same way as would the research worker himself.

The recent development of services for supplying microfilm and photostat copies of papers not normally available except in the largest libraries has been a further notable advance in solving the problem of making the literature of science more easily accessible to those who need it—though it does not, of course, assist the scientist in his primary task of discovering the existence of papers which will be helpful to him.

In fields in which the greatest amount of work has already been done, the accumulation of literature tends to be so great that the mechanical task of sorting it out is unduly onerous. To overcome this difficulty, some degree of mechanization has been introduced into library practice. In the commonest form, cards are punched in patterns characteristic of the information they carry, and machines—sometimes very complicated—sort out from the remainder the cards carrying any desired combination of marks. Progress has been made, too, in rendering even more concise the symbolism commonly used in most branches of science; in organic chemistry, in particular, several methods have been developed expressing structural formulae unequivocally in code form.

In spite of all that has been done to help him, the average research worker, unless he happens to be able to make full use of a well-endowed library large enough to offer some of the special services described above, is still very largely dependent on his own efforts, and on the service provided by the abstracting journals. As such special library facilities are likely to expand only slowly, no rapid alteration in the situation is to be foreseen. Accordingly, it is perhaps appropriate to suggest one way—too widely neglected—in which the scientist, especially the younger scientist, can be taught to help himself more effectively. This is by the inclusion, at an early stage in the university science course, of detailed instruction in the use of the science library. At present, far too many scientists graduate without ever having thoroughly learnt where and how they can most probably expect to find information on any particular subject. To track down information speedily and successfully requires both a wide general knowledge of the bibliography of science and a knowledge of modern library practice—in particular, knowledge of the use of card indexes prepared according to the conventional systems of classification. There are, it is true, several excellent books on this subject, but they seem to be little known and less appreciated. The burden of scientific knowledge is today too vast for anybody to carry more than a tiny fraction of it constantly in mind, and many will refuse to rely on memory when important issues are at stake. The really essential thing is to know where to find information quickly when it is needed. A former Master of Balliol College, Oxford, is said to have advised all freshmen at their first interview with him to 'verify your references and don't buy your wine in the town.' We can whole-heartedly recommend at least the first half of this admonition to all aspiring scientists. The scientist who can make the best possible use of whatever library facilities he possesses gains so great an advantage that the matter is too important to be left to chance. Every student of science should be specifically instructed in the bibliography of science.

Editor: E. J. HOLMYARD, M.A., M.Sc., D.Litt., F.R.I.C
Deputy Editor: TREVOR I. WILLIAMS, B.A., B.Sc., D.Phil.
Foreign Editor: J. A. WILCKEN, B.Sc., Ph.D.

Imperial Chemical Industries, Nobel House, Buckingham Gate, London, S.W.1.
Communications to the Editors should be addressed to 26 Dover Street, London, W.1.

Nuclear reactors in scientific experiments

SIR JOHN COCKCROFT

Nuclear physics has very rapidly become one of the most important and fruitful branches of science. Even at this very early stage of development its wealth of possibilities is plainly apparent, and the control of matter which it is placing at man's disposal seems likely to be immense. Sir John Cockcroft, director of the Atomic Energy Research Establishment at Harwell, England, here discusses some of the ways in which nuclear reactors are applied.

The progress of nuclear physics has depended very much on the development of new techniques. The simple scintillation counter, together with α-particles from radium, provided for Rutherford and Marsden the tool which led to the concept of the nuclear atom. Later, in Rutherford's hands, they were used to discover the artificial disintegration of elements. The development of electronic counters for protons and α-particles, together with the Wilson chamber, made possible the discovery of the neutron. The high-voltage particle accelerator and the cyclotron, by greatly increasing the intensity of sources of protons, neutrons, and α-particles, made possible a new range of experiments, a range which is still developing.

The atomic pile or nuclear reactor in its turn has provided us with another tool of great importance, and already many new experiments are being made possible. The reason is that the nuclear reactor provides a very large number of neutrons from the fission of uranium. Inside the pile we have a source of fast neutrons, with energies of the order of 10^6 electron volts (eV), or velocities of the order of 10^9 cm/sec. The pile slows these fast neutrons to thermal velocities. Outside the pile we can therefore provide a source of slow neutrons, with energies of the order of 0·02–1000 eV, or velocities of $2{\cdot}2 \times 10^5$ cm/sec to 200 times this value. If we compare the intensities of slow-neutron beams which can be provided by the pile with those provided by the cyclotron we find that a typical research pile has a substantial advantage, an advantage which enables us to make experiments not possible on the cyclotron.

In order to understand these experiments it is necessary to know something about the characteristics of atomic piles. Figure 1 shows the principle of construction of a graphite pile.

A mass of several hundred tons of pure graphite is interspersed with a lattice of uranium metal rods. This is usually known as the reacting core. Surrounding the core is a layer of graphite known as the reflector, since it serves to reflect most of the neutrons escaping from the core back into the reacting system. Round the reflector is a shield of concrete which absorbs the greater part of the radiations escaping through the reflector, and so prevents the radiation outside the reactor from reaching an intensity harmful to health.

The intensity of the nuclear reaction inside the reactor is governed by so-called control rods, which are metal rods containing materials of high neutron absorption, such as cadmium or boron. These rods are used to control the death-rate of neutrons inside the reactor. The course of the nuclear reaction is determined by the reproduction-constant of the neutrons. A neutron produces a fission of uranium, and in so doing releases perhaps two neutrons in the splitting-up of the uranium nucleus. A number of these neutrons escape from the reactor; some of them are swallowed up in reactor materials without producing fission, but on the average a fraction K survives to produce a further fission. If K is greater than unity, the neutron population and the intensity of reaction increase. If K is less than unity, the population decreases.

When the control rods are fully inserted, K is less than unity, and the chain reaction does not develop. To start up the reaction we withdraw the control rods until K is a little over unity. We then find that the neutron population, and with it the heat developed and the general radiation intensity, increase as

$$e^{4 \times 10^4 (K-1)t}$$

where t is measured in hours. An excess K of 2·5 parts in a hundred thousand gives the pile a period of one hour. In practice we withdraw the control rods to give the reactor a period of a few minutes; we allow the pile power to increase to the desired value, and then insert the control rods to make K equal to unity. The power then stabilizes

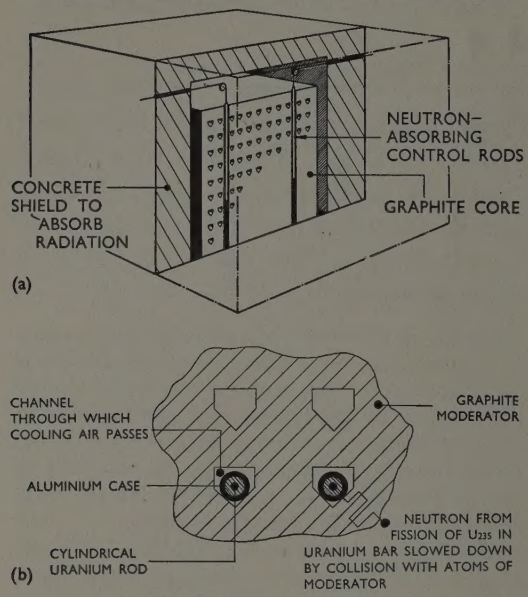

NEUTRON-ABSORBING CONTROL RODS
CONCRETE SHIELD TO ABSORB RADIATION
GRAPHITE CORE
(a)
CHANNEL THROUGH WHICH COOLING AIR PASSES
GRAPHITE MODERATOR
ALUMINIUM CASE
NEUTRON FROM FISSION OF U235 IN URANIUM BAR SLOWED DOWN BY COLLISION WITH ATOMS OF MODERATOR
CYLINDRICAL URANIUM ROD
(b)

FIGURE 1 – (a) *Section through graphite pile.* (b) *Section through graphite pile, showing method of embedding uranium rods, encased in aluminium, in the graphite moderator.*

itself and remains very constant—to within a few parts in ten thousand.

The reproduction constant is affected slightly by changes of temperature and barometric pressure: a pressure change of a few millibars is detectable. Small adjustments must therefore be made to control the rod positions, and this is usually done by a servo-mechanism actuated by a radiation intensity meter.

For experimental work we are interested in the flux of neutrons—the number crossing one square centimetre in a second at the point of the experiment. We also require to know the velocity spectrum of the neutrons. The neutron flux is directly proportional to the amount of heat developed in the reactor, and more specifically to the amount of heat developed per unit mass of the fissile isotope U235. This is because the heat developed, which comes mainly from the kinetic energy of the fission fragments, is proportional to the number of fissions, and this in turn determines the neutron flux.

Simple reactors such as the Harwell GLEEP (figure 3), which have very little cooling, can operate comfortably at a power level of 100 kilowatts. By fairly simple air cooling the second Harwell reactor develops a thermal energy equivalent to several thousand kilowatts. Water cooling of the uranium, or more intensive air cooling, allows still higher energy releases to be obtained.

The second Harwell reactor will have a maximum flux of fast and slow neutrons of the order of $2{\cdot}5 \times 10^{12}$ neutrons/cm^2/sec. The graphite research reactor being built at the Brookhaven National Laboratory in the United States will have a slow neutron flux of 5×10^{12} neutrons/cm^2/sec. [1]. Heavy-water reactors have a higher neutron flux for a given total power. This is because they use substantially less uranium metal, owing to the higher potential K of a heavy-water reactor. For a fixed power, the power per unit mass of fissile material is therefore higher, and, in general, neutron fluxes are an order of magnitude higher. The Canadian research reactor at Chalk River has been stated [2] to provide a slow neutron flux of 3×10^{13} neutrons/cm^2/sec.

The neutron flux is a maximum at the centre of the pile, and follows a cosine distribution decreasing by a factor of 5 to 10 at the edge of the reacting core:

$$\cos\frac{\pi x}{a},\ \cos\frac{\pi y}{b},\ \cos\frac{\pi z}{c},$$

where the approximate reacting core dimensions are $2a$, $2b$, $2c$. The flux decreases through the reflector, and falls by a factor of about 10 for each foot of concrete in the shield.

The region of high flux can be extended into the shield, and brought to its face, by piercing the shield with experimental holes which may be of 4–12 inches in diameter. These holes are filled with graphite if we wish to have a high flux of slow neutrons near the surface of the reactor. They are left empty if we wish to work with fast

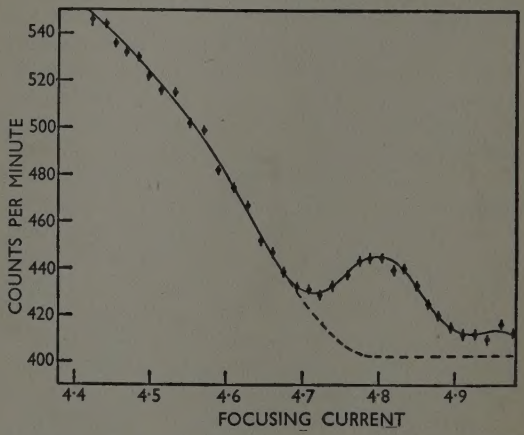


FIGURE 2 – *Distribution of energy in gamma-rays emitted from paraffin after neutron capture. (After Elliott.)*

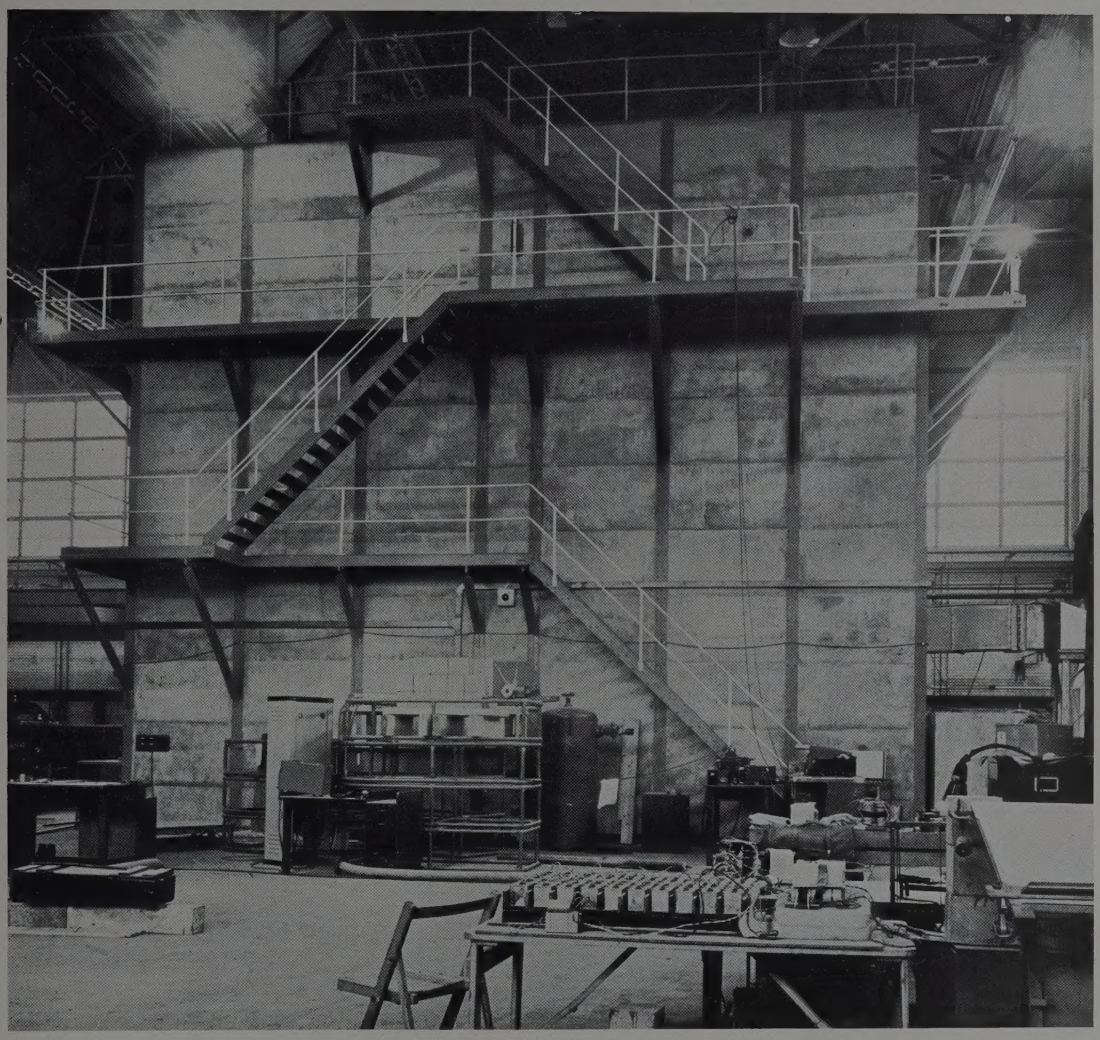


FIGURE 3 – *Face of the Harwell GLEEP.* (*Crown copyright reserved.*)

neutrons. We also provide in the shield a 'thermal column' of graphite extending from the reflector to the face of the shield. Neutrons diffuse along this graphite column, and would emerge at the face were they not stopped by a cadmium shutter which absorbs the thermal neutrons. When the thermal neutrons are stopped, gamma-rays are emitted by the capturing nuclei, so that it is necessary to fit a lead shield outside the cadmium to absorb these rays.

The thermal-neutron flux decreases as we go outward along the thermal column. When the reactor central flux is of the order of 10^{12}, the flux two feet back from the face of the thermal column will be about 6×10^{8}.

EXPERIMENTS WITH REACTORS

1. *Neutron beam experiments*

Beams of slow neutrons can be obtained from the pile by removing the concrete plug from one of the experimental holes and inserting graphite together with suitable collimating tubes, or by using the thermal column.

An interesting group of experiments measures the energies of the gamma-rays produced when slow neutrons are captured by different nuclei. This provides a measure of the energy with which successive neutrons are bound to the nucleus, and thus will give us some guide to nuclear structure.

The earliest example of this process to be studied was the capture of neutrons by hydrogen.

Lea [3] identified these 'capture' gamma-rays and approximately measured the cross-section for capture. Chadwick and Goldhaber [4] studied the reverse process of the photo-disintegration of the deuteron by the Th.C^{11} gamma-rays, and from measurement of the energy of the disintegration protons deduced a value for the binding energy of the deuteron of 2·1 MeV. Since that time, the photo-disintegration process has been more accurately studied by using gamma-rays from a high-voltage generator.

Recently, Elliott and Bell [5] have used the Chalk River pile to determine the energy of the captured gamma-rays very precisely. In these experiments a slab of paraffin 25 in. square by 5 in. depth was placed in the thermal column of the pile. Thermal neutrons are captured in the paraffin, producing gamma-rays. These gamma-rays are collimated by a conical shell of lead having a half-angle of 15°. The gamma-rays strike a uranium radiator and eject photo-electrons from the *K* and *L* shells of the uranium atom. The photo-electrons enter a β-spectrometer, which measures their energies and so enables the gamma-ray energy to be deduced. Elliott's results are shown in figure 2. It will be seen that there are, first, a continuous distribution of Compton electrons due to the scattering of gamma-rays; second, two peaks corresponding to photo-electrons ejected by the gamma-rays from the *K* and *L* shells of uranium.

From the position of these peaks, the energy of the capture gamma-rays is 2·236 ± 0·005 MeV. This was checked by comparison with the Th.C^{11} line at 2·620 MeV. To this energy must be added the small energy of recoil of the nuclei on capture of the neutron. We arrive then at the binding energy of the neutron:

$$2{\cdot}237 \pm 0{\cdot}005 \text{ MeV}.$$

This is about 50 keV higher than previously accepted values, obtained from photo-disintegration experiments using gamma-rays from a van de Graaff generator, and depending therefore on accurate calibration of the generator.

Since the proton mass is tied to the deuteron mass by the mass spectrograph bracket,

$$2H_1 - D = 1{\cdot}433 \text{ MeV}$$

and

$$D - (H_1 + n) = 2{\cdot}237 \text{ MeV}$$

$$n - H_1 = 0{\cdot}804 \text{ MeV}.$$

Thus the neutron mass is increased and becomes 1·008992 ± 0·000010, an increase of about 53×10^{-6}.

2. *Other experiments on gamma-ray capture*

Experiments on the energies of capture gamma-rays in other elements are proceeding and are of importance. Nuclear engineers are interested from a severely practical point of view, since they need to know the energies of the gamma-rays released from structural materials such as steel in the pile, for this affects the design of the shield.

The gamma-ray energies are measured either by the lens β-spectrometer, or, with more resolution, by a pair-spectrometer in which the positive and negative electrons created by the high-energy gammas are separately focused and the sum of their energies is measured. Figure 4 shows results obtained by B. B. Kinsey [6] at Chalk River on the energy spectrum of the gamma-rays of capture in pure nickel.

3. *Neutron reactions*

The intense source of thermal neutrons facilitates the study of slow-neutron reactions.

An interesting example is the reaction:

$$B^{10} + n = Li^{7x} + \alpha$$

An excited nucleus of Li is formed, and this gives rise to the well-known gamma-ray of 478 keV energy. When this line is observed in the β-spectrometer it is seen to be broad in comparison with the photo-electron lines ejected from a thin gold radiator by other gamma-ray lines of similar energy. The broadening can be explained by the Doppler effect due to emission of the gamma-rays by the Li^{7x} nucleus in flight. Since the nucleus is in flight for 3×10^{-13} second it follows that the gamma-rays must be emitted in less than this time. By mixing different materials with the boron target, the Li^{7x} nucleus can be slowed down

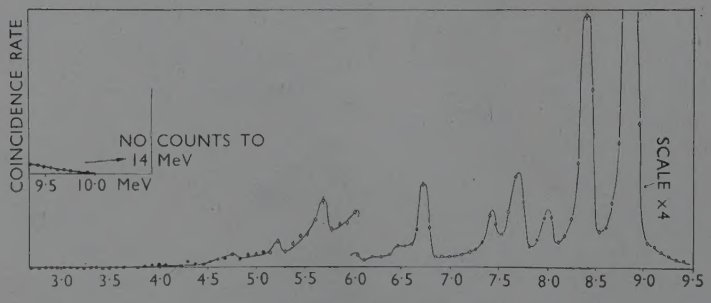


FIGURE 4 – *Energy spectrum of gamma-rays of capture in pure nickel. (After Kinsey.)*

more rapidly, and in this way Elliott and Bell [7] have found that its lifetime is 3×10^{-14} second.

The Harwell pile has been used to show that He^3 can be transformed into tritium by capture of slow neutrons, and the cross-section for this reaction has been shown to be very high.

The reaction is: $He^3 + n \rightarrow He^4 \rightarrow H^1 + H^3$. This is an interesting case of a reverse reaction, for tritium, produced in nuclear reactors, is the usual source of supply of He^3 in the United States, and will be so in due course in Britain.

Flowers and Batchelor [8] filled a pressure ionization chamber with atmospheric helium, of which 1·2 in 10 million parts is He^3. The protons from the reaction were detected, and their energy was measured, by an electronic pulse analyser. Their energy and numbers were compared with the protons from the transmutation:

$$N^{14} + n \rightarrow N^{15} \rightarrow C^{14} + p.$$

The cross-section for the $He^3(np)H^3$ reaction was found to have the high value of 3700×10^{-24} cm^2.

4. *Neutron lifetime experiment*

An experiment of considerable theoretical interest is the measurement of the neutron lifetime being carried out by Snell [9] at Oakridge and Robson [10] at Chalk River. The neutron is expected to decay into a proton with emission of a negative electron:

$$n \rightarrow p + \varepsilon^-,$$

the electron energy being 804 keV.

Application of standard beta-decay theory leads to a predicted half-life of 20 minutes using the old mass of the neutron, and about 14 minutes using the new mass. This prediction results from the standard relation between the upper limit of the beta spectrum and the half-life.

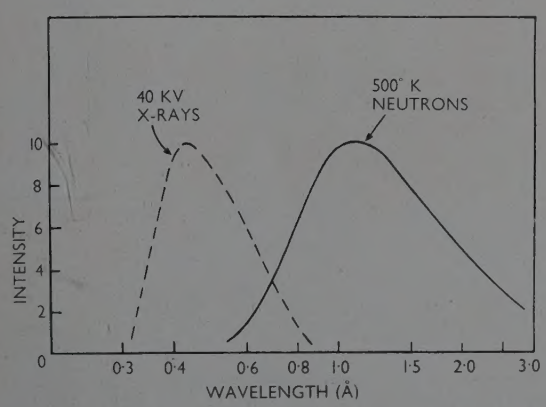


FIGURE 5 – *Wave-length distribution for 40 kV X-rays and for neutrons from thermal column of typical pile.*

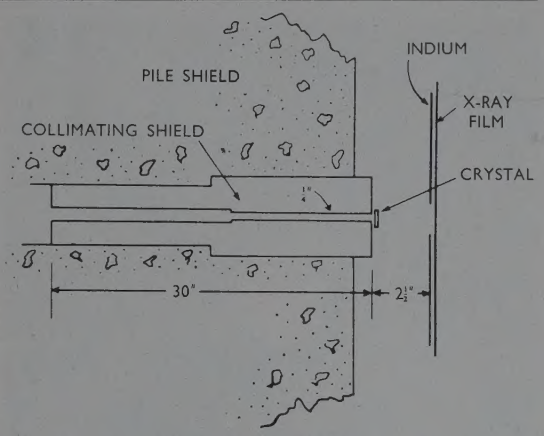


FIGURE 6 – *Method of illustrating neutron diffraction by the Laue method. (After Schull and Wollan.)*

Slow neutrons from the thermal column of the Chalk River pile are collimated into a beam of $3\frac{1}{2}$ inches diameter, in which are about 10^9 neutrons per second, and pass into a vacuum chamber through a thin window. A transverse magnetic field behind the window clears the beam of secondary electrons. Inside the vacuum chamber the beam passes between two electrodes. One, cylindrical, electrode is held at + 20 kV with respect to earth. The other electrode is earthed, and forms the entrance aperture to a thin-lens magnetic spectrometer. The field between these electrodes accelerates protons which result from decay of the neutrons, so that they pass through into the lens spectrometer and are focused on the first electrode of an electron multiplier.

The background counting rate was about 60 per minute. A peak of a further 80 counts per minute was observed on top of this background when the magnetic field was adjusted for protons of an energy corresponding to 20 kV. From the number of protons recorded, the half-life of the neutron was calculated to be between 9 and 18 minutes.

NEUTRON DIFFRACTION

Neutrons, like all other particles, must be associated with waves having a wave-length

$$\lambda = \frac{h}{mv},$$

and since $m = 1{\cdot}66 \times 10^{-24}$ g

and $v = 2{\cdot}8 \times 10^5$ cm/sec at 500° K,

$h = 6{\cdot}620 \times 10^{-27}$ g cm^2/sec

$\lambda = 1{\cdot}4 \times 10^{-8}$ cm.

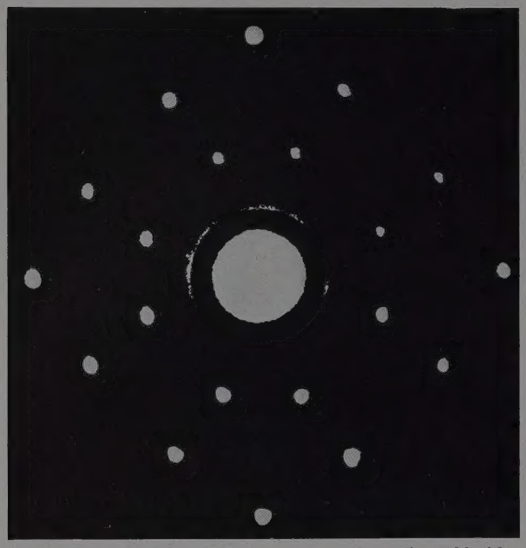


FIGURE 7 – *Neutron diffraction pattern for sodium chloride. The neutron beam is passed parallel to one of the crystallographic axes.*

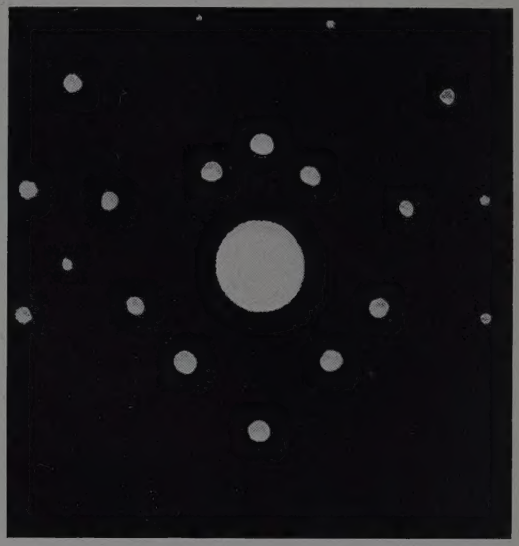


FIGURE 9 – *Neutron diffraction pattern for sodium nitrate. This is a rhombohedral crystal, and as a result the pattern is more complex than for lithium fluoride or sodium chloride.*

We should therefore expect diffraction phenomena very similar to those characteristic of X-rays.

Figure 5 shows the wave-length distribution for 40 kV X-rays, and for neutrons coming out of the thermal column of a typical graphite pile, the temperature being about 500° K. Note the important difference of sharp monochromatic lines in the copper X-ray spectrum (figure 11).

The simplest method of showing neutron diffraction in the case of a continuous wave-length distribution is by the Laue method, and figure 6 illustrates the experimental arrangement used by Schull and Wollan [11] at Oakridge to demonstrate this effect.

FIGURE 8 – *Neutron diffraction pattern for lithium fluoride, under the same conditions as for figure 7.*

The beam of thermal neutrons is collimated through a shield block 30 inches in length, with a final limiting aperture of $\frac{1}{4}$-inch diameter. A crystal is mounted across the beam, and the pattern is recorded on a sheet of X-ray film aligned perpendicularly to the axis of the collimated beam, with a crystal-to-film separation of $2\frac{1}{2}$ in. Since X-ray film is not sensitive to neutrons it is activated by placing an indium foil in front of it. Neutrons are captured in the indium, and produce a radioactive isotope from which electrons are emitted to darken the film at points where the diffraction pattern renders the neutron density high. Exposures of 10 hours are required, but the addition of fluorescent screen material to the indium sheet seems likely to reduce the time substantially—probably to the X-ray time of 15 minutes.

The next figures (7, 8) show the observed pattern for a sodium chloride crystal and a lithium fluoride crystal, when the neutron beam is passed parallel to one of the crystallographic axes. These crystals have face-centred cubic lattices.

The inner ring of spots corresponds to reflections from planes (3,1,1) and their permutations.

The outer ring of spots corresponds to reflections from planes (4,0,2) and (4,2,2) and permutations. Figure 9 shows the pattern from a rhombohedral crystal of sodium nitrate, which is more complicated.

DIFFRACTION OF CRYSTALLINE POWDERS

The most useful technique in the application of neutron diffraction is the Debye-Scherrer powder diffraction method [12], in which a crystalline powder is irradiated with monochromatic

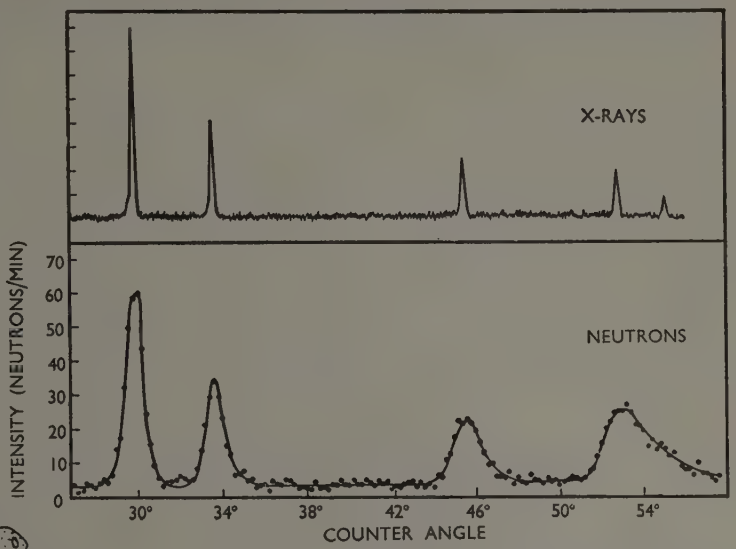


FIGURE 11 – *Comparison of results of powder diffraction with X-rays and with neutrons, by copper powder.*

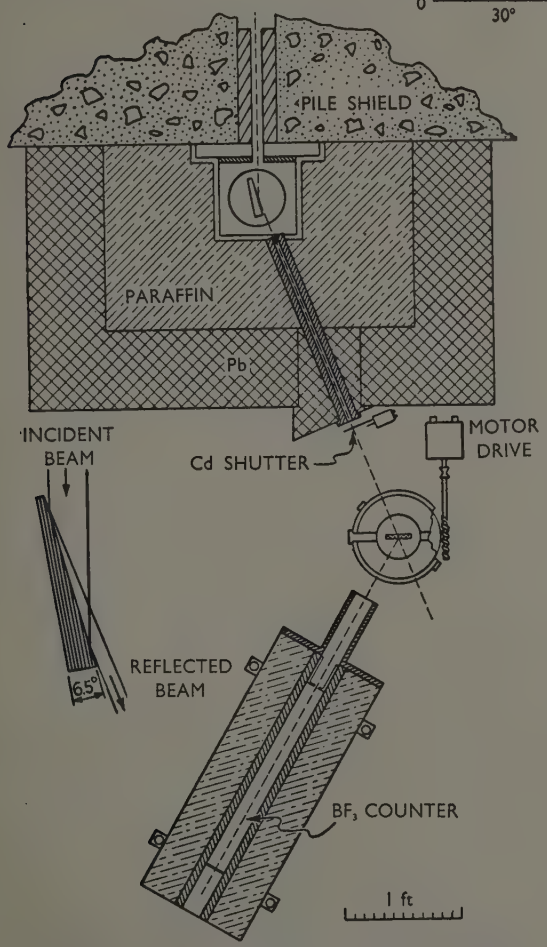


FIGURE 10 – *Neutron diffraction by the Debye-Scherrer powder method. A monochromatic neutron beam is obtained by Bragg reflection from a single crystal.*

neutrons obtained by Bragg reflection from a single crystal. Figure 10 illustrates the method, and figure 11 shows the comparative results obtained with X-rays and neutrons for copper powder. It will be seen that the resolution obtained by neutrons is less than with X-rays. The intensity of the X-ray lines decreases for higher angles, owing to the decrease in form-factor, whereas no such decrease occurs for neutrons.

Figure 12 shows the results obtained for manganous oxide. In this case there is a great difference in the pattern of the peaks, owing to the negative scattering of neutrons by manganese nuclei as compared with oxygen nuclei. With X-rays the scattering is in the same phase.

In these two cases neutron technique does not add to our knowledge of structures, but figures 13 and 14 illustrate cases where neutron diffraction can supply additional information. Figure 13 shows the diffraction pattern obtained with sodium hydride. The X-ray pattern is characterized only by the sodium positions, which take up a face-centred cubic structure. The difference between the X-ray and neutron patterns is due to the hydrogen, and a detailed examination shows that the hydrogen positions are similar to those of the chlorine in sodium chloride.

The second example is the study of alloys, where the form-factors of the components with X-rays are so similar that it is not possible to pick out the position of the components. Consider the structure of an iron-cobalt alloy. Figure 14 shows

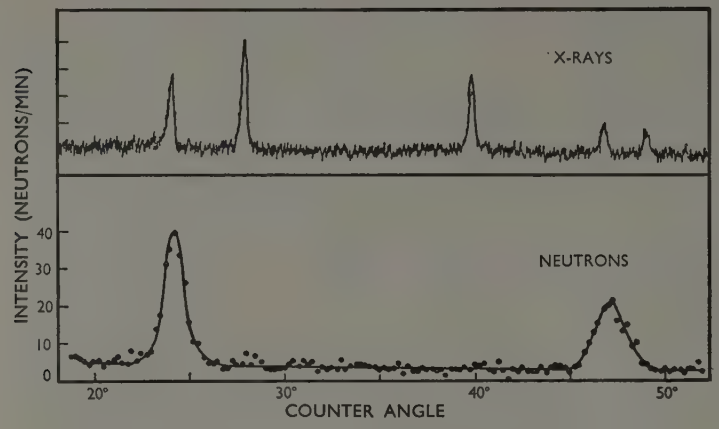


FIGURE 12 – *Comparison of results of powder diffraction with X-rays and neutrons by manganous oxide.*

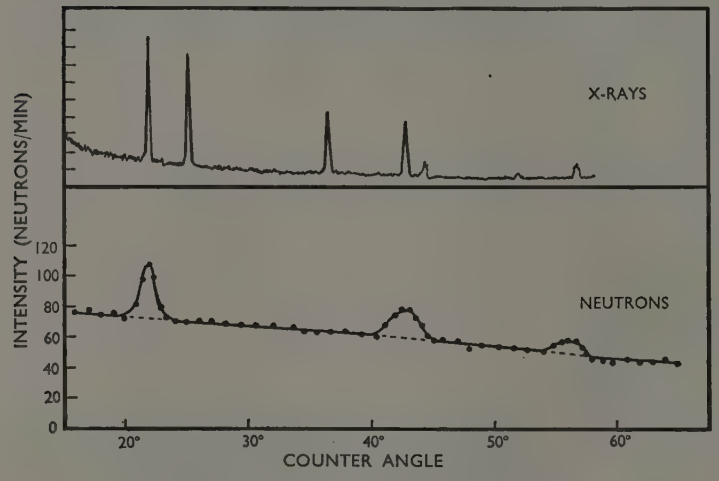


FIGURE 13 – *Diffraction patterns for sodium hydride.*

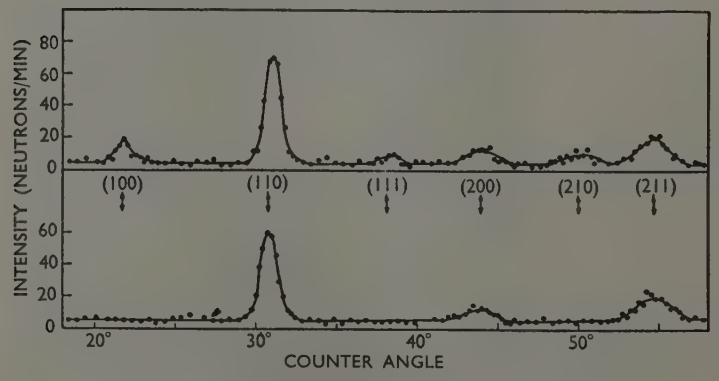


FIGURE 14 – *Comparison of neutron diffraction patterns for ordered (above) and disordered (below) iron-cobalt alloy.*

the neutron pattern for an ordered Fe/Co alloy, and the different pattern for a disordered alloy. In the ordered structure the cobalt atoms are at the centres, and the iron atoms at the corners, of single cubes.

In general, it would appear that neutron diffraction is likely to make substantial contributions to studies of metal structure. The disadvantages of the method are due to the rather lengthy time required to obtain readings, and to the fact that we cannot have atomic piles in every laboratory. We do hope, however, to make facilities available at Harwell for such studies.

THE EFFECT OF NEUTRON IRRADIATION ON SOLIDS

When fast neutrons from fission pass through crystalline material, they lose energy by elastic collisions with the lattice atoms. The result of these collisions is to displace the atoms from their position in the lattice to interstitial positions. Thus, it has been calculated that a 2 MeV neutron in the course of being slowed down to thermal energies would displace about 500 atoms in beryllium metal, and about 2500 in beryllium oxide.

The result of this action is to change the physical properties of the medium; in particular the electrical and thermal conductivities are altered and the elasticity and mechanical properties change.

We are interested in these phenomena from the point of view of pile technology. We are also interested from a more fundamental point of view. In particular we should like to be able to study the history of the displaced atoms, and to see whether or not they return to holes left by displacement of

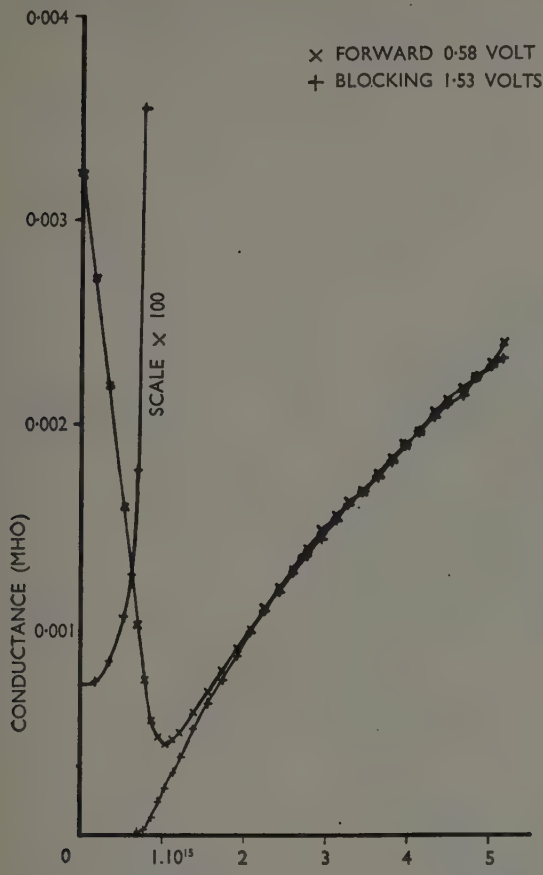


FIGURE 15 – *Effect of neutron irradiation on the conductance of a germanium rectifier at 40° C.*

other atoms, and how this process is affected by temperature.

These studies have been started at Harwell by irradiating the rectifying modification of germanium in the pile. Similar and earlier experiments have been carried out by Lark-Horovitz [13].

The properties of the rectifier are characterized by the conductivity in the forward and in the backward (or blocking) directions. In semi-conducting germanium the forward conductivity at a temperature of 40° C will be about 0·003 reciprocal ohm, while in the blocking direction it will be of the order of 10^{-5} reciprocal ohm. One of these semi-conductors was irradiated in GLEEP for a period of about a day. Any change would presumably be proportional to the time × neutron-flux at the position of the specimen, and proportional therefore to *nvt*, where *n* is the number of neutrons and *v* the velocity. One day's irradiation in the centre of GLEEP corresponds to a value of *nvt* of about 10^{15}.

The results of this experiment, carried out by T. M. Fry at Harwell, are shown in figure 15. It will be seen that the forward conductivity drops by a factor of about eight to a minimum for an *nvt* value of 10^{15}, while the blocking conductivity increases by a factor of about 25, so that forward and backward conductivity become almost equal and the crystal is no longer a rectifier. It behaves now like a second type of germanium known as the P type, as distinct from the normal N type which rectifies.

These results can be interpreted on the generally accepted picture of conductivity in semi-conductors, assuming that about one atom in a million is displaced to an interstitial position. In this position they trap electrons from the conduction band and reduce the forward conductivity.

Figures 2 and 10 are reproduced by permission of *The Physical Review*; Figures 11–14 are reproduced by permission of *Science*; Figures 5–9 are reproduced by permission of the U.S. Atomic Energy Commission.

REFERENCES

[1] Borst, L. B., Fox, M., Gurinsky, D. H., Caplan, I., *et al. Phys. Rev.*, **74**, 1883, 1948.

[2] National Research Council of Canada Report CRR401, p. 1.

[3] Lea, D. E. *Proc. Roy. Soc.*, A, **150**, 637, 1935.

[4] Chadwick, J., and Goldhaber, M. *Proc. Roy. Soc.*, A, **151**, 479, 1935.

[5] Elliott, L. G., and Bell, R. E. *Phys. Rev.*, **74**, 1552, 1948.

[6] Kinsey, B. B. Canada, Chalk River. (*Unpublished.*)

[7] Elliott, L. G., and Bell, R. E. *Phys. Rev.*, **74**, 1869, 1948.

[8] Flowers, B. H., Batchelor, R., Whittaker, A., and Eppstein, J. S. *Nature*, **163**, 211, 1949.

[9] Snell, H., and Miller, L. C. *Phys. Rev.*, **74**, 1217. Abstract F12, 1948.

[10] Robson. Canada, Chalk River.

[11] Schull, C. G., Wollan, E. O., and Marney, M. C. *Phys. Rev.*, **73**, 527, 1948.

[12] Schull, C. G., Wollan, E. O., Morton, G. A., and Davidson, W. L. *Phys. Rev.*, **73**, 842, 1948.

[13] Johnson, W. E., and Lark-Horovitz, K. *Phys. Rev.*, **76**, 442, 1949.

The clocks of Christiaan Huygens

C. A. CROMMELIN

The construction of clocks occupied much of Christiaan Huygens's time throughout his life. In 1656 he invented the pendulum clock, and in 1675 he discovered the principle of the spiral-spring regulator. He also constructed a variety of other ingenious timepieces such as the *remontoire* clock. In addition he contributed notably to the theory of harmonic motions, though the calculation of the periods of some of his oscillators was impossible, owing to the limitations of mathematical theory, until very many years after his death.

It is a well-known fact that Christiaan Huygens invented the pendulum clock in 1656, and in 1675 the timekeeper regulated by means of a balance and spiral spring. The fundamental difference is that the former depends on the force of gravity, whereas the latter is independent (or nearly independent) of it. Huygens made the pendulum strictly isochronic by applying cycloidal cheeks at the top. The balance needed no isochronizing; it is isochronic in itself, and performs, like the cycloidal pendulum, strictly isochronic harmonic vibrations.

These two inventions have endured, and still form the basis of clockmaking all over the world. It is, on the other hand, not generally known that Huygens, not being sure that the pendulum and the balance would prove to be by far the best, invented and tested a number of other mechanisms with well-defined natural frequencies to regulate the timepieces; first, to improve the pendulum and the balance if possible, and, second, with a special view to the determination of longitude at sea. It is these clocks that I shall describe in this article, after a few notes concerning the life of Huygens.

Huygens was born in 1629 at The Hague, as the second son of Constantijn Huygens, a well-known poet and statesman. He studied law and mathematics at Leiden University (1645–7), continued his studies at the *Collegium Arausiacum* at Breda (1647–9), and then settled in The Hague, where he lived at home until 1666 and devoted himself entirely to his mathematical, mechanical, physical, and astronomical studies. The fruits of these years were, *inter alia*, the theory of probabilities, the laws of elastic concussion and centrifugal force, the construction of the pendulum clock (figure 2), theoretical and practical geometrical optics (lens-grinding), and the discovery of Saturn's rings and its satellite Titan.

In 1666, Huygens accepted an invitation from the French statesman Colbert to settle in Paris as a member of the newly founded *Académie des Sciences*. He lived in Paris until 1681, and these years were extremely fruitful. In 1673 Huygens published one of his masterpieces, the *Horologium Oscillatorium*, dedicated to Louis XIV, in which he describes not only his improved pendulum clock, but also very much theoretical work, including the complete theory of the rigid pendulum (moment of inertia and the centre of oscillation), the mechanical properties of the cycloid, and the theory of evolutes and involutes. This book is one of the classical works in the history of mechanics; in it Huygens laid the foundations of rigid dynamics.

In 1673, he invented his gunpowder machine—a very primitive affair indeed, more fit for demonstration than for practical use, but nevertheless involving the principle of the internal combustion engine. In 1675, he invented the balance-wheel and spiral-spring regulator of a chronometer, and in the same year he gave the general theory of isochronism and of harmonic vibrations.

The discovery of double refraction in Iceland-spar by Erasmus Bartolinus in 1670 induced Huygens to resume his optical studies. The idea of an undulatory transmission of light ripened in his mind. In 1677 he explained completely, with the aid of his now world-famous principle, the laws of double refraction, and in the following year he communicated his undulatory theory of light to the *Académie*, though he did not publish it before 1690, in a small book, *Traité de la Lumière*, his second immortal masterpiece.

In 1681 Huygens returned to The Hague. After the death of his father (1687), he lived for the greatest part of his life at Hofwijck, a small country seat at the village of Voorburg, near The Hague, but he had also lodgings in The Hague where he sometimes spent a couple of months.

His most important work during these later years of his life was, besides his work on timepieces and lens-grinding, the exact formulation of the principle of the conservation of mechanical energy—to him an axiom, and a principle which he had used often in his researches, but never enunciated clearly until 1693.

In 1695 Huygens died in his lodgings at The Hague. It was indeed well quoted of him:

Credo equidem, nec vana fides, genus esse deorum.

(*Aen. IV*, 12)

We have already mentioned that Huygens, during the greatest part of his life and even in the last years before his death, devoted a considerable amount of work and time to the invention and construction of all sorts of clocks.

The first one, after the invention of the pendulum clock, was a timepiece with a conical pendulum, invented probably in 1659 or 1660 and constructed about 1667 or 1668. This pendulum differs essentially from the back-and-forth oscillating pendulum. The weight describes a horizontal circle continuously; the motion of the train of gears and of the hands on the dial is also continuous; and the clock does not tick, as there is no escapement. Huygens writes in a letter (1667): '. . . *une autre manière d'horloge . . . avec un pendule qui tourne en rond*,' and in another one (1668): '*J'en ay icy une du mouvement circulaire . . . qui va assez bien et sans bruit.*'

FIGURE 1 – *Christiaan Huygens at the age of* 50, *sculptured in relief, from real life in white marble by Jean Jacques Clérion* (1679) *at Paris.* (*National Museum of the History of Science at Leiden.*)

Of this timepiece, Huygens devised two models. We know the first one only by two rough sketches in manuscripts in the Leiden university library, and by a very short and very indistinct description in the same manuscripts. There is an arrangement to make the period isochronic, i.e. in this case independent of the value of the angle of elevation, but this apparatus is clumsy rather than elegant and we shall not describe it. It has very probably never been constructed or tested.

Huygens' second isochronic conical pendulum, on the contrary, is most ingenious—even really beautiful (figure 3). The well-known formula for the period of a conical pendulum is

$$T = 2\pi\sqrt{\left(\frac{l\cos\alpha}{g}\right)}$$

in which l = length of pendulum, α = angle of elevation, and g = acceleration due to gravity. The problem is thus to construct a pendulum so that $l\cos\alpha$ remains always constant.

Huygens' construction is represented schematically in figure 6 in the text. The metallic rod XO rotates by the action of the weight or the spring of the clock. To this axis is attached at E, and supported by the metal rod XD, a metallic curve ED in the form of an evolute of the parabola FOF', so that the axis, the rod, and the curve form a rigid whole, the parabola in the figure not indicating metal but being drawn for the sake of the proof which follows.

The pendulum is attached at D. When the machine is at rest, the wire of the pendulum follows the curve and the weight is at O, but when the axis rotates, the weight is elevated by the centrifugal force to A, some point of the parabola; the pendulum adopts the form $DP'A$ ($P'A$ being tangential to the evolute and normal to the parabola), and the weight rotates with an angle of elevation α on a circle situated on the paraboloid of revolution around the axis.

When this is well understood, the demonstration of the isochronism is simple. As a matter of fact, nothing in the motion of the pendulum changes when P is fixed, so that $l = PA$, the true length of the pendulum, and thus $l\cos\alpha = PC$, i.e. the projection of the normal AP on the X axis. According to a well-known property of the parabola, this projection is constant and equals p, when

$$y^2 = 2px$$

FIGURE 2 – *Pendulum clock made by Salomon Coster in* 1657 *at The Hague under Huygens' personal supervision. It is the oldest pendulum clock in existence.* (*National Museum of the History of Science at Leiden.*)

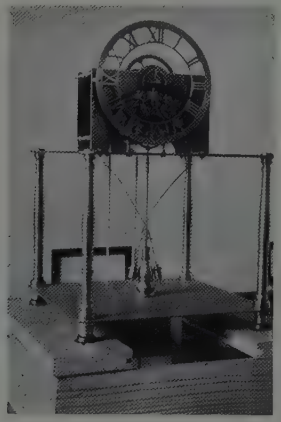


FIGURE 3 – *Reconstruction of Huygens' clock with parabolic conical pendulum.* (*National Museum of the History of Science at Leiden.*)

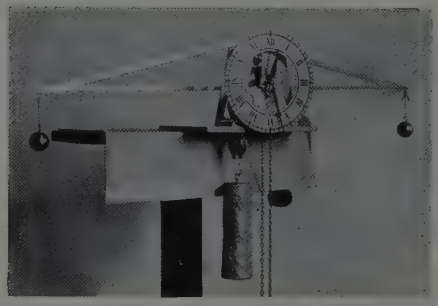


FIGURE 4 – *Reconstruction of Huygens' clock with the* Libra isochronis recursibus. (*National Museum of the History of Science at Leiden.*)

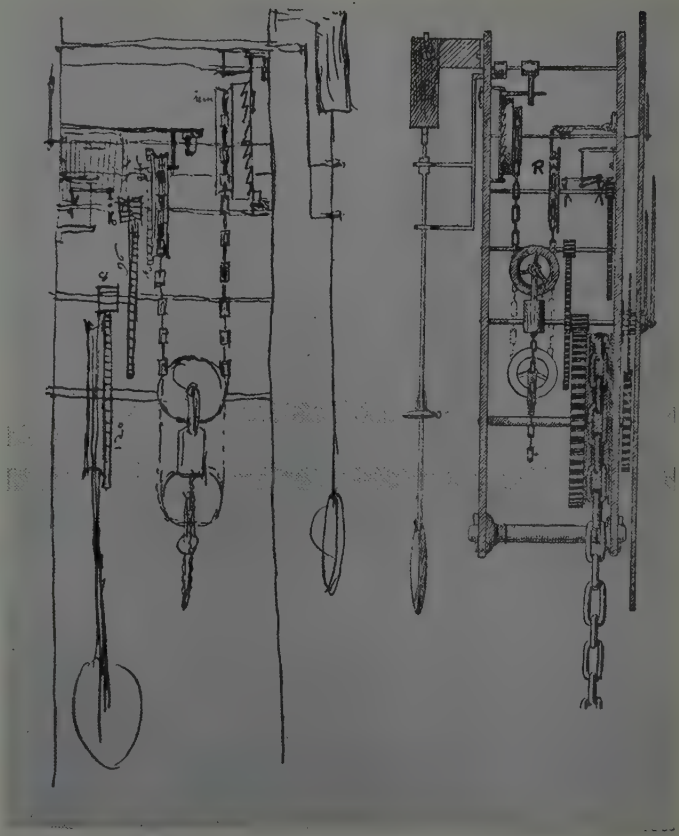


FIGURE 5 – *Marine* remontoire *clock, drawings by Huygens.* (*From the manuscripts in the Leiden University Library.*)

is the equation of the parabola. Hence it is proved that the period

$$T = 2\pi\sqrt{\left(\frac{l\cos\alpha}{g}\right)} = 2\pi\sqrt{\left(\frac{p}{g}\right)}$$

is constant and independent of α.

We have already mentioned that Huygens always had in mind the determination of longitude on board ship by means of his newly invented pendulum clock, but such a clock requires a very firm and steady mounting, which of course cannot be achieved on board ship. All trials of a pendulum clock on a sea voyage proved to be failures, but Huygens, notwithstanding those failures, continued all his life to design new models of pendulum clocks intended for use at sea.

The first model is the *remontoire* clock of 1664, which, as R. T. Gould says with good reason, 'includes some of the most ingenious, elaborate, beautiful, and useless contrivances ever made by man.'[1] The short pendulum (with cycloidal cheeks) swings, not under the action of the driving weight, but under that of a very small weight in the interior of the clock, the train of gears and the hands on the dial being at rest (figure 5). Every half-minute, contact between the pendulum and the train of gears is established by an automatic device (too complicated to be described here); the small weight is remounted very rapidly by the driving weight; and the cogwheels begin to turn, but only just enough to advance the hour hand and the minute hand for half a minute. Then the action begins again, and so on for every half-minute.

The advantage of the *remontoire* consists in the fact that the pendulum swings under the action of the small weight, and is connected with the escapement only by means of the crown wheel. Its period is thus entirely independent of any irregularities in the train of gears, and of the thickness of the oil, etc., the only function of the main weight and of the train of gears being the rapid rewinding of the small weight each half-minute. It is, however, difficult to understand Huygens' strong recommendation that *remontoire* be used on board ship, for its complicated mechanism renders it most unsuitable for this purpose.

Huygens' second model was the marine clock of about 1672 (figure 7). This clock was spring-driven and had three dials, a big one for the minutes, and two small ones inside the big one for the hours and the seconds. It was suspended in

[1] R. T. Gould. *The Marine Chronometer*, p. 28 (London, 1923).

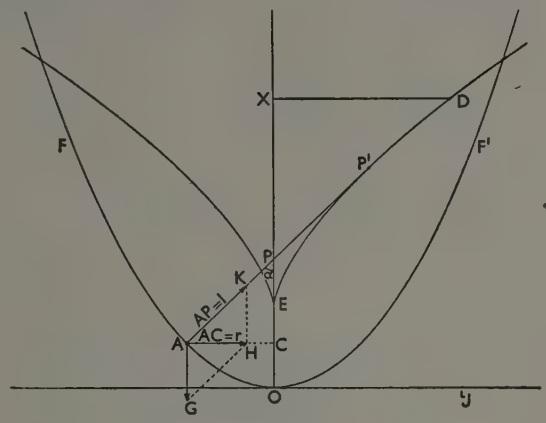


FIGURE 6

gimbals (Cardan suspension) in order that it should not follow the movements of the ship. At the bottom of this suspension was a heavy leaden weight for purposes of stabilization. The lens-shaped weight of the pendulum was suspended on two thin wires, both with cycloidal cheeks at the top, so that it had the form of a V.

In 1675 Huygens invented a timepiece regulated by a balance-wheel and spiral spring, i.e. a timepiece independent (or nearly independent) of the force of gravity and its direction. This invention is sometimes attributed to Robert Hooke, the well-known secretary of the Royal Society, but in my opinion unjustly. Hooke contested Huygens' priority; he spoke of his 'watches regulated by springs,' but, as far as I know, never described the nature of his springs, or the way in which they were attached to the balance.[2] It should be noted

[2] R. Hooke, Cutlerian Lectures, reprint by R. T. Gunther, *Early Science in Oxford*, vol. VIII.

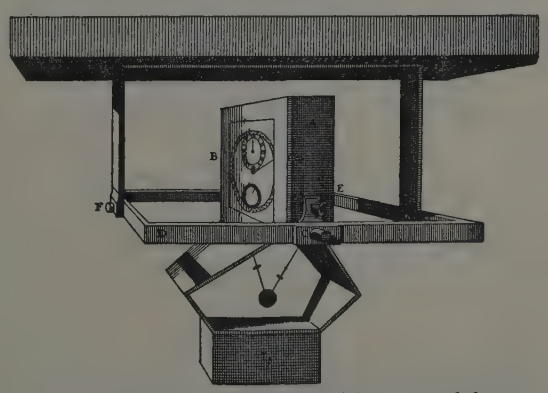


FIGURE 7.– *Marine clock with pendulum suspended on two wires.* (*From a drawing in Huygens'* Horologium oscillatorium.)

that the spiral spring is the only one that has been kept in use for chronometric purposes up to the present day; it is harmonic and isochronic, properties of which Huygens was well aware.

Huygens soon observed that the characteristic period of the spiral spring was influenced in a high degree by the temperature—much more so than that of the pendulum—and this was the reason why he did not continue his experiments on the balance spring, compensation devices being totally unknown at that time.

Wanting to keep the balance movement but to get rid of the spring, he invented a suspension of the balance by means of three threads; he called this pendulum the *Pendulum cylindricum trichordon.* When the balance (a rather heavy hollow cylinder) is moved from its dead-point, it is slightly raised, and the threads are deviated from their original vertical position. If then left to itself, the balance performs a to-and-fro rotating movement. The clocks with this pendulum were again designed for marine use; they were constructed about 1685 and were probably put to the test by Huygens himself on the Zuyder Zee. It is difficult to understand why Huygens returned here to a pendulum swinging under the action of the force of gravity, which he had avoided carefully in the case of the balance and spring.

Notwithstanding all the failures of the pendulum clocks on board ship, Huygens never gave up all hope of success in this matter, and even in the last years of his life he invented several new models of pendulums for marine use.

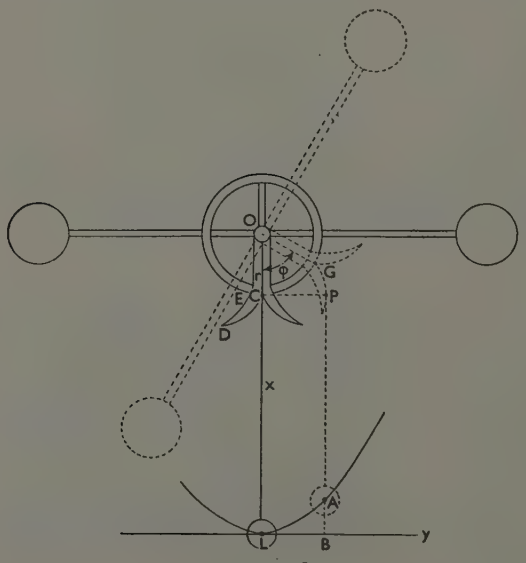


FIGURE 8

Very interesting is what he calls the *Libratio isochrona melior praecedente* of 1693 ('the isochronic balance better than the previous one,' this previous one being a simpler model not described here). It has never had any practical value, but the mathematical demonstration is very elegant (see figure 8). A large and heavy balance swings slowly on a horizontal axis, under the action of the force of gravity. Rigidly connected with the balance is a vertical rod OC, with two cheeks DE, not cycloidal, but of the form of an involute of the circle with radius $r = OC$. Between the cheeks in C a string is attached bearing the weight L; this string with its weight is not a pendulum, and remains (or is supposed to remain) in a vertical position when the balance swings. The balance with the rod, but without the weight L, is supposed to be in indifferent equilibrium; with the weight L, but without the cheeks, it would be a rigid pendulum and thus approximately isochronic. The cheeks make the swingings strictly isochronic.

To prove this theorem, we first calculate the trajectory which the weight will describe when the balance swings. P, the point where the spring detaches itself from the involute GP, remains always at the same height as C, CP being tangential to the circle and normal to the involute. Now

$$\text{arc } GP = \frac{CP^2}{2r}$$

(found by integration, the equation of the involute being given).

Taking OL as X axis and LB as Y axis, arc $GP = AB = x$, and $LB = CP = y$, therefore

$$x = \frac{y^2}{2r}, \text{ or}$$

$$y^2 = 2rx.$$

The trajectory of L is thus a parabola with r as parameter.

The moment, M, of the force which the weight exerts on P is

$$M = mgCP = mgy$$

(m being the mass of the weight);

$$y = CP = \text{arc } CG = \varphi r,$$

thus

$$M = mg\varphi r;$$

φ being the angle of rotation of the balance, we have

$$\frac{M}{\varphi} = mgr = \text{const.}$$

Therefore the swingings are harmonic and strictly isochronic.

Figure 4 represents an improved model of the latter clock, which Huygens calls the *Libra isochronis recursibus*. A long but very light triangular balance swings slowly; at both ends weights are attached, by means of strings, between arcs of the form of involutes of a circle. This timekeeper was doubtless an improvement, from a technical point of view; its oscillations are also strictly isochronic, but the proof of the isochronism is rather complicated and too long to be given here.

The mathematical proofs of isochronism as I have given them in two cases are modern, and not in the form in which Huygens gave them. Huygens knew quite well the methods of Descartes' analytical geometry and used them when necessary, but he preferred pure geometrical proofs. Most of his innumerable mathematical and mechanical demonstrations were purely geometrical: always most ingenious, generally not easy to read, and always cumbersome—from a modern point of view at least.

It is noteworthy that Huygens never mentions or calculates the periods of his sometimes rather complicated swinging systems, and there is every reason to believe that he was unable to do so, simply because the mathematical methods of his time were inadequate.

Nowadays we calculate all such periods by an ingenious and simple theorem which holds for all swinging systems, the swings of which are harmonic and the position of which can at any given time be defined by one single parameter ψ.

In this case, the potential energy E_p and the kinetic energy E_k can always be written as follows:

$$E_p = \tfrac{1}{2}A\psi^2 \quad \text{and} \quad E_k = \tfrac{1}{2}B\left(\frac{\mathrm{d}\psi}{\mathrm{d}t}\right)^2,$$

A and B being constants independent of the time. The period is then

$$T = 2\pi\sqrt{\frac{B}{A}}.$$

The proof of this theorem may be easily given by substituting a harmonic function for ψ, for instance:

$$\psi = \cos\frac{2\pi t}{T}$$

and by introducing the condition that

$E_p + E_k = \text{const.}$, i.e. independent of time.

By means of this theorem one finds, for instance:
For the simple cycloidal pendulum:

$$T = 2\pi\sqrt{\frac{4r}{g}}$$

(r being the radius of the circle which generates the cycloid);
For the pendulum cylindricum trichordon:

$$T = 2\pi\sqrt{\frac{Ql}{mgr^2}}$$

(l being the length of the strings, r the radius of the balance and Q the moment of inertia of the balance);
For the libra isochrona melior praecedente:

$$T = 2\pi\sqrt{\frac{Q}{mgr}}$$

(identical with period of the rigid pendulum).

This theorem is extremely useful in calculating such periods; it holds also in many other cases, for instance for a liquid oscillating in a U-shaped tube, and even for electrical oscillations.

REFERENCES

[1] *Œuvres complètes de Christiaan Huygens, publiées par la Société hollandaise des Sciences à Haarlem; éditées par la maison Martinus Nijhoff, la Haye, imprimées par la maison J. Enschedé en Zonen, Haarlem.* 22 volumes, quarto. Vol. I bears the date 1888, vol. XXII is in the press. Volumes XVII and XVIII contain Huygens' researches in the field of horology.

[2] CROMMELIN, C. A. Six papers in the Dutch periodicals *Physica*, *Nederlandsch Tijdschrift voor Natuurkunde*, and *Intern. Mathematisch Tijdschrift* and in the Belgian *Wis- en Natuurkundig Tijdschrift* (1931–40). These six papers were summarized, enlarged, and elaborated in the *Journal suisse d'horlogerie*, vol. 72 (1947), p. 189 (with all the mathematical and mechanical demonstrations *in extenso*).

Amber inclusions

G. KIRCHNER

Amber inclusions are of exceptional interest to the palaeontologist, for no other natural form of prolonged preservation leaves the specimens in such perfect condition. In recent years their significance has increased as a result of the discovery of large numbers of aquatic forms, formerly regarded as being very rare. It is therefore a cause for profound regret to learn that the unique collection of amber acquired by the University of Königsberg—much of it derived from the famous Palmnicken amber mines—was destroyed during the last war.

The trees which exuded amber were conifers, but they have long been extinct. They bequeathed their hardened resin as a yellow stone-like substance, which so often contains relics of early forms of life that it has claims to be considered the best of all natural preservatives. While calcite, pyrites, and flint have also transmitted to us interesting forms of prehistoric life, these media modified the captured bodies through diagenesis, and thus more or less changed their original appearance. Amber resin, however, was completely innocuous, and it began to solidify almost immediately after the engulfment of an object. During the short period of its existence in the liquid state it offered little resistance to intrusion, whether by insects, by feathers carried into it by the wind, by leaves and other parts of plants, or by small bodies in general. Even water could be engulfed to a certain degree, as has been proved by the discovery of inclusions of aqueous origin.

Until recently, the amber inclusions generally known originated from the fauna and flora of the subtropical land where the amber trees grew in mixed forests. It may be assumed that several different types of conifers provided similar resins, but, although many trees of geologic age are known to us in detail, we have very few indications as to the appearance of the amber conifers. Their only traces are the small inclusions of flowers, wood splinters, needles, and twigs, which, though confirming types, do not reveal much about the actual identity of the trees.

The problem has been widely studied, but it cannot be said to have been solved. It is perhaps true that palaeobotanists have not yet fully considered the suggestion that amber trees may have been swamp-trees related to the Tertiary swamp-cypress. This possibility is now being investigated, partly because twigs of cupressoids appear more frequently among amber inclusions than the needles of firs and pines, and partly on account of the large variety of aquatic inclusions recently discovered.

The amber collection of Königsberg University —unhappily destroyed during the war of 1939–45 —contained a vast number of animal inclusions, and numerous specimens containing arthropods (insects, centipedes, spiders, etc.) had been collected through decades in the amber works in the neighbourhood, where raw amber was treated. The few cases in which aquatic animals were found among the inclusions were, however, believed to have been caused by fortuitous circumstances, and the idea that they might have resulted from the resin entering the water, and there engulfing the animal, had not been conceived.

This conception took shape after repeated observations in the well-known amber works at Palmnicken—where numerous and frequently recurring specimens of this type were discovered—provided overwhelming evidence that aquatic inclusions could not be the result of accidental occurrences. It was found that aqueous inclusions originated both in the sea and in fresh water, and those discovered are by now quite as numerous as the terrestrial ones.

Little information has so far been obtained about the vegetative and physical processes which led to the hardening of the resin, and no complete chemical analysis of amber has been achieved. If amber could be melted without decomposition, the process of solidification could be followed, and perhaps experimentally controlled. At present, any conclusions about the possible properties of the liquid form have to be based on investigations of the solid, for this, on heating, decomposes into the so-called oil of amber and a black, pitch-like residue. On dry distillation, amber yields from 3 to 8 per cent. of succinic acid. It is probably not a single chemical individual but a mixture of various resinous substances with a chemical constitution approximating to $C_{10}H_{16}O$; it also

PLATE I – *Specimens of plant and animal inclusions in amber.*

PLATE 2 – *Specimens of plant and animal inclusions in amber.*

PLATE 3 – *Specimens of plant and animal inclusions in amber, including some aquatic forms.*

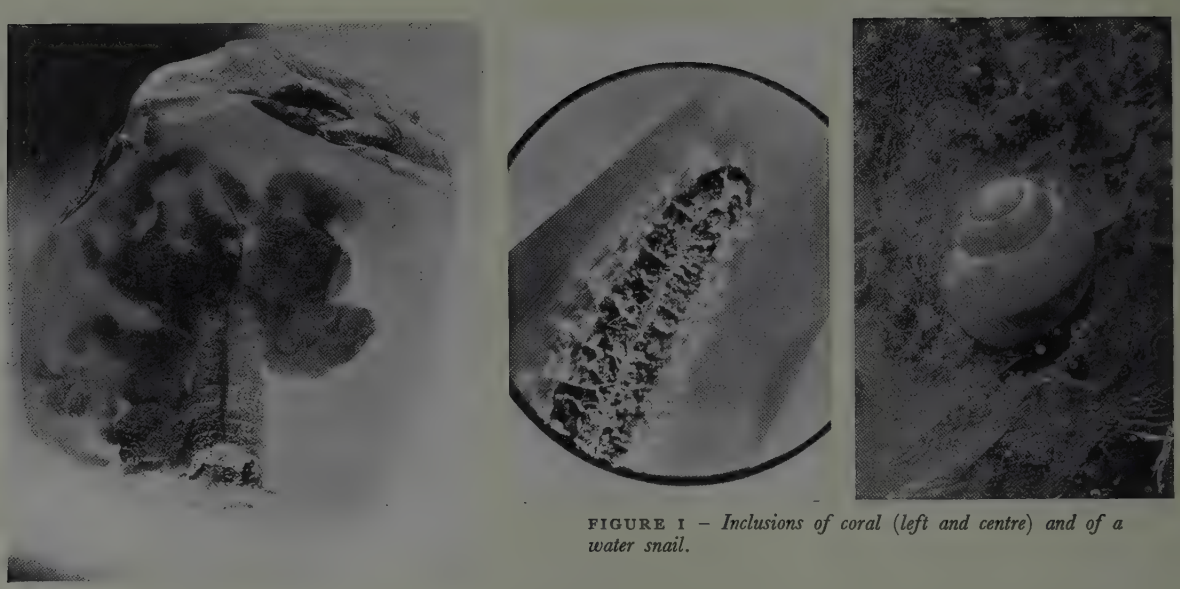


FIGURE 1 – *Inclusions of coral (left and centre) and of a water snail.*

contains small amounts of inorganic compounds such as the chlorides and sulphates of calcium and magnesium. In the case of aqueous inclusions, these salts may well have been introduced in the water.

The resin which flowed from the cells of the woody tissues was a quasi-living substance, and the masses of it which spread outside (usually 1–3 kg but exceptionally 6–9 kg), to cover a wound in the tissue, solidified under unknown conditions. A fact of which we can be certain is that the solidification must have taken place rapidly; the resin was thus able to transmit to us the unaltered appearance of the animal or plant which happened at that moment to be in contact with it. The inclusions, especially when total, are intact, and have been preserved in their natural form. If the quantity of the flowing resin was insufficient, the object remained in the border of the hardening mass. The opening thus left resulted in atmospheric oxidation, causing a reddening of the resin, and small cracks would develop as the amber weathered. These might influence the transparency of the matrix. Inclusion of large numbers of minute air bubbles renders amber turbid.

X-ray examination has shown that amber is amorphous. Its specific gravity is usually between 1·06 and 1·08, though somewhat lower and higher figures have been recorded for occasional specimens. The specific gravity of the liquid balm was possibly lower than that of the solid, and the surface tension was doubtless low. Owing to its greater density, the liquid would sink in water, and this explains the inclusions of such organisms as *Volvocales*, *Cyanophyceae*, *Protococcaceae*, and radiolarians; even drops of water were sometimes included in smooth-walled cavities. Water was not absorbed during the process of solidification, and the drops in amber have therefore been preserved for countless thousands of years. It has also been observed that the vacuoles in enclosed plankton algae are still filled with the aqueous liquid which they contained when the algae were alive. It would be an interesting task for further amber research to subject these liquids to a microchemical analysis; among other things such research might reveal whether the sea-water of the Tertiary age possessed a similar composition to that of the seas of today.

The discovery of very large numbers of aquatic amber inclusions of an amazing variety stimulated scientists to investigate the processes leading to inclusion and solidification; this widened the scope of amber research, which had previously been focused on inclusions of terrestrial origin.

The first aim of the new investigations was to determine the miscibility with water of a material similar in character to the amber resin. The inclusion of objects of aquatic origin in the resin during its solidification could be possible only if its miscibility with water were incomplete. A familiar

example of incomplete miscibility is provided by the system phenol-water, and as phenol is the basis of various resinous substances it seemed as good a substance to use for comparison as any other; moreover, it has the same specific gravity as amber. At 20° C, the solubility of phenol in water is 8 and the solubility of water in phenol is 28. Above 66° C phenol and water are completely miscible. The maximum temperature of the water of the subtropical Tertiary sea was almost certainly not higher than 25° C, and thus, if the comparison between phenol and amber balm be regarded as allowable, we may assume that amber balm and water were in fact only partially miscible under the then prevailing conditions. Incidentally, it may be noted that the hardness of amber hardened on or in wood is much higher than that of amber with aquatic inclusions, which shows such little resistance that it often breaks when manipulated.

Aquatic inclusions usually occur in massive amber, while those of terrestrial origin appear to be found exclusively in a shaly variety of the resin. Submersion in water evidently provided conditions for solidification very different from those which prevailed for the resin in the atmosphere, where each layer hardened as it emerged from the tissues of the trunk.

The large number of specimens found in the open-cast amber works at Palmnicken provided rich material for research, and a full examination of nearly all the samples was carried out. Among them were part of the arm of a starfish, a young fish, a very good example of a polychaete, the imprint of a fish's tail, some mussels, and several corals. These discoveries brought considerable progress, but the work was still far from complete, especially with regard to evidence about haliplankton and limnoplankton, the presence of which seemed probable after the discovery of algae and corals in amber. While these could often be detected by the naked eye, plankton required thin sections of the amber for intensive microscopic examination. The results proved satisfactory in the end, but within the limited space of this article only a few of them can be mentioned.

Four stages of the amber-alga *Discophyton electroneion* could be examined in detail. The presence of this alga, belonging to the *Cyanophyceae*, offers one of the best proofs of the existence of at least one type of swamp-tree among the resin-exuding trees, for it contains the blue colouring-matter phycocyanin, which occurs freely in swamp vegetation. *Discophyton* may be reckoned the leading amber inclusion, providing as it does about 70 per cent. of all the aquatic inclusions.

With regard to size, corals and hydrocorals are of foremost importance among the marine inclusions. Hydrocorals were colony-forming polyps with a massive calcareous external skeleton surrounding the tube-shaped body; until lately they were classed with the genuine corals. Hydrocorals were exclusively marine animals and formed dense, massive reefs. Their nearest relation among recent forms is *Millepora alcicornis*. They lived in the littoral zone, not in deep water. We can imagine that amber-tree wood, cast into the sea by the wind or some other natural agency, exuded its resin on a reef near the shore. Some of the resin attached itself to the jagged rocks and hardened there, and, if not swept away by the waves, took a passive part in the fate of the reef. Sinking with the floor of the sea, the reef may have encountered water rich in iron and in hydrogen sulphide, for the hard parts of the hydrocorals in these amber inclusions show a content of iron sulphide the composition of which approximates to that of iron pyrites. It seems likely that the fragments of free iron pyrites which occur in some amber mines are remnants of the pyritized hydrocoral reefs of the Tertiary sea.

Genuine corals are represented by several types. They are closely similar to the present red coral of the Mediterranean in the formation of their branches and skeletons. Their tentacles are not feathered but smooth, though they show the octagonal arrangement of the octocorals. The tentacles of the specimens in some of the inclusions are partly fully extended, partly withdrawn as in defence. The preservation of the very sensitive tentacles of the living coral indicates the rapidity with which the engulfment took place; any biologist would have to work extremely quickly to achieve a similar preservation.

A specimen of *Carophyllia turbinolida* is of special interest. This coral builds solitarily and is shaped like a closed cup. Its identification was possible only because one of the cups had apparently been split open accidentally and thus presented itself to investigation as if a special section of it had been made.

Until recently, the inclusions of terrestrial origin had provided the principal contribution to the natural history of amber. New problems have arisen through the discovery of aqueous inclusions, and the solution of these problems will lead to a wider and fuller knowledge of the geology of the amber formations of the Samland.

The Arabic achievement in physics

H. J. J. WINTER

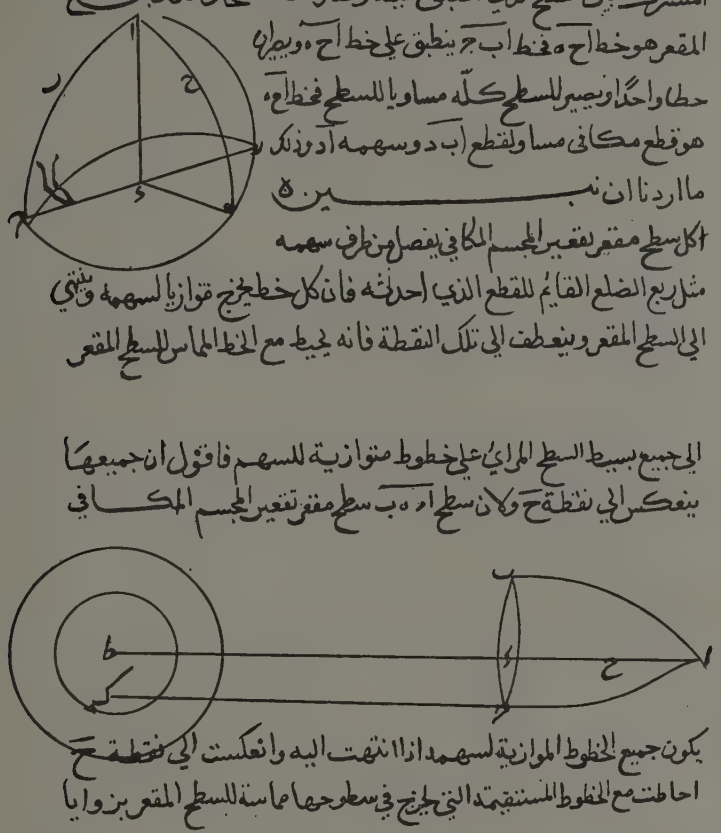
Arabic contributions to chemistry are widely known and appreciated; it is, however, much less generally realized that there was also a notable Arabic contribution to astronomy and to physics, especially in optics, mechanics, and hydrostatics. With the encouragement of such patrons as Frederick II of Sicily and Alfonso X of León and Castile these contributions of Muslim scholars became known in western Europe and profoundly influenced the researches of Robert Grosseteste, Roger Bacon, Leonardo da Vinci, Johannes Kepler, and other scientists.

On the decline of the Roman Empire, and particularly after the closing of the schools of learning in Athens in the year A.D. 529 by the Emperor Justinian, the legacy of Greek science passed to the East, mainly owing to the efforts of the Nestorians in such centres as Antioch, Edessa, and Nisibis, and to a lesser extent through the waning Alexandrian School in Egypt. Nestorians were particularly well received at the Sāsānian capital of Jundīshāpūr in south-west Persia, and here arose a great centre of learning, where east and west mingled, and where the Greek rationalist outlook on the universe held its own against oriental mysticism until the triumph of Islām. When, on the establishment of the 'Abbāsid caliphate in Baghdād, the leadership in culture passed to that city around A.D. 750, the scientists of Islām were able to build their knowledge upon both the geometrical methods of the Greeks and the analytical approach of the Hindus—though they generally favoured the former, which indeed proved ultimately to be a limitation, as it had been with the Greeks themselves.

The Arabic language was an admirable medium for the transference of the new thought, and during the period A.D. 750–900 the classics of Greek physics were sought out, translated with commendable industry, and sometimes improved upon. Moreover, algebraical and trigonometrical ideas were derived from the Sanskrit. During this time of translation, some of the physical works of Aristotle were made available by Ḥunain ibn Isḥāq (809–877) and his many collaborators; Al-Kindī wrote an improved version of the *Optics* of Euclid; Thābit ibn Qurra studied the 'Roman' steelyard; and the Banū Mūsā (the three sons of Mūsā ibn Shākir) completed *c.* 860 *The Book of Artifices*, a treatise on mechanics. Indeed, it will be seen presently that the Arabic contribution to physics was mainly in optics and mechanics, particularly the former.

Arabic science reached its zenith between about A.D. 900 and 1100, and in this phase we encounter a galaxy of great intellects: men of wide learning, tolerance, and travel, who mastered all the knowledge of their day and reproduced it in their encyclopaedic writings. Among them were Ar-Rāzī (Rhazes), a celebrated physician, who also studied optics and the properties of matter and motion, space, and time; Ibn Sīnā (Avicenna), 980–1037, eminent as philosopher, physicist, and physician, who wrote a great work on physics, a beautiful copy of which was obtained by Sir Francis Younghusband from the oasis of Yarkand and is now with the Royal Asiatic Society; Ibn al-Haitham (965–1039), one of the greatest optical students of all time; and Al-Bīrūnī ('The Master') —973–1048—a contemporary of Firdausī at the Court of Maḥmūd of Ghazna. Al-Bīrūnī was a many-sided genius, whose work in several branches of learning remains classic, and who made in particular a careful study of the specific gravities of metals and precious stones.

We select Ibn al-Haitham, known in medieval Europe as Alhazen, for particular note. Born at Basra, he spent the last years of his life in the vicinity of Al-Azhār in Cairo. His greatest work is the *Optics* (*Kitāb al-manāzir*), a Latin version of which appeared in 1572 [1]. Until lately the Arabic original was believed lost, but a manuscript has been found in Istanbul and is the basis of some recent researches by Muṣṭafā Nazīf Bey [2]. Al-Haitham not only improved upon the knowledge of optical reflection inherited from the Greeks, but was the first to make an elaborate investigation of refraction. By competent mathematical investigation he extended the laws of reflection, which had been considered mainly by Euclid and other Greek thinkers in relation to plane mirrors, to the case of concave and parabolic mirrors [3], and he undertook the actual construction of steel reflectors by means of a kind of



Parts of a MS. of the work of Ibn al-Haitham. The centre figure shows parallel rays from the sun striking a parabolic mirror.

(*Reproduced by courtesy of the India Office Library*)

lathe. In this way he was able to discover spherical aberration (though he failed to consider the caustic curve), and, on the basis of the conics of Apollonius, to establish an exact focus in the case of the paraboloid. This happy combination of analysis and synthesis places Al-Haitham among the great scientists. His methods influenced not only some of his successors in the east, but also Robert Grosseteste, John Peckham, Roger Bacon, Witelo, Leonardo da Vinci, and Johannes Kepler in the west. The application of rigid mathematical methods to physical problems enabled Al-Haitham to determine the point of reflection on a concave spherical mirror when the positions of the object and the eye are known; the resulting equation of the fourth degree was solved by the intersection of a circle and a hyperbola. The elaboration of such work, involving cubic equations, from the initial treatises of Archimedes and Apollonius, was a unique Arabic achievement, leading to a solution of certain physical problems and to the greatest algebraical treatise of medieval times, the *Algebra* of 'Umar Khayyām. The first use of the camera obscura is ascribed to Al-Haitham; he also made a study of the onset of twilight [4], in which he gives 19° as the angle of depression of the sun below the horizon for its occurrence; and he gave the luminous object as the source of light, as did Ibn-Sīnā and Al-Bīrūnī, in contradistinction from Euclid and Ptolemy, who had believed that the rays originated from the eye.

The new departure made by Al-Haitham lay, however, in the subject of refraction. A remarkable experimental investigation of refraction had been made in

antiquity and is generally attributed to Ptolemy, but Al-Haitham's work reads in places like a seventeenth-century treatise. He related the change in direction of a ray of light on entering a medium of different density to an alteration in the velocity of the light, the light travelling more slowly in the denser medium; there were two properties, transparency and density, the former facilitating motion, the latter retarding it. By imagining the velocity of the incident ray to be the resultant of two components, one in the direction of the normal to the surface of separation of the two media and the other parallel to that surface, he was able, by reducing the latter velocity, to account for a position of the refracted ray nearer to the normal when the second medium is the denser, and, conversely, for a movement of the ray away from the normal when the second medium is the rarer. It is interesting to note that while Al-Haitham's interpretation accorded with experimental fact, Sir Isaac Newton's theory, of some seven hundred years later, did not; for Newton, assuming that light consists of corpuscles endowed with great velocity,[1] increased the normal component of this velocity so that the resultant value became greater in the denser medium. Newton's investigations into the nature of light, however, were more profound, for Al-Haitham hardly went beyond the fact of a very great velocity. There are, nevertheless, five outstanding features in Al-Haitham's work: firstly, he was clearly aware of the principle of inertia, later stated as Newton's First Law of Motion, in his conception of the path of a ray of light; secondly, his handling of the mechanism of refraction reveals a competent knowledge of the rectangle of forces, though he does not seem to have considered the possibility of altering the normal component of the velocity as Newton did; thirdly, his statement that a ray of light takes the path, through a medium, which is the 'easier and quicker,' brings him near to Fermat's principle of least time; fourthly, he knew the first law of refraction, that the incident and refracted rays and the normal to the surface of separation lie in the same plane; and finally, though he failed to discover the second law, which Snell found in 1621, his experimental results indicate that he handled apparatus competently and fully realized the necessity of the empirical approach to knowledge. It is a pity that Al-Haitham did not perceive the sine relationship. The Greek method of reckoning by chords, and the sine of an angle (*jyā*) as used in the Hindu Siddhāntas, had already become known to the Muslim scientists; in particular, Al-Battānī, of Sabian origin, who died in A.D. 929, had already extended trigonometry to spherical triangles. Al-Haitham also investigated the magnification produced by a lens, and the phenomenon of atmospheric refraction.

In the year 1258 Nasīr ad-Dīn aṭ-Ṭūsī[2] was appointed chief astronomer, and an observatory was erected, at Marāghah in Adharbaijān, on the order of the Mongol, Hulāgū Khān. With the aid of assistants gathered from Damascus, Mausil, Tiflīs, and Kazvīn, Aṭ-Ṭūsī made beautiful astronomical instruments of exquisite workmanship, and completed, under Abaqā Khān, the famous Ilkhānian astronomical tables. Aṭ-Ṭūsī, as one might expect, was also interested in optics, and wrote about reflection, making a version of the *Optics* of Euclid as Al-Kindī had done earlier, but he seems to have failed to understand refraction; he was primarily a geometrician in outlook and was restricted by Euclidean methods. One of his pupils, Quṭb ad-Dīn ash-Shīrāzī (1236–1311) did, however, study the refraction of light in the raindrop, and was instrumental in calling the attention of his own pupil, Kamāl ad-Dīn al-Fārisī (died *c.* 1320), to the *Kitāb al-Manāzir* of Al-Haitham, Book VII of which, on refraction, had apparently been ignored. Al-Fārisī, in the early fourteenth century, made an abridgment from an autograph copy of Al-Haitham, and then wrote a valuable commentary with his own observations, entitled *Tanqīḥ al-Manāzir*.

Questions on optical refraction had engaged the attention of Muslim scholars in the first half of the thirteenth century, owing to the enthusiasm and broad outlook of Frederick II of Sicily, who linked Islām with Latin Christendom. His influence lasted, long after his burial in Palermo in 1250, well into the fourteenth and fifteenth centuries. He was—with Raymond I, Archbishop of Toledo, in the twelfth century, and Alfonso X of León and Castile in the late thirteenth century—one of the agents who inspired the translation of Arabic treatises, some on physics, into Latin. In correspondence with scholars in the Muslim world Frederick II posed questions such as: Why do oars immersed in water appear bent? Why does Canopus appear larger when near the horizon, even when the atmosphere contains no moisture? Frederick's foundation of the university of Naples in 1224, with its collection of Arabic manuscripts,

[1] Ibn Sīnā had also used this hypothesis.

[2] Nasīr ad-Dīn (1201–74) of Ṭus in Khurāsān. Many of the 'Arabic' scientists were actually Persians: we use the term Arabic rather than Arab.

and his transmission of translations to Bologna and Paris, were instrumental in bringing the latest Muslim ideas into Europe; no doubt the optical theories of Witelo and Roger Bacon owe something to the university of Paris.

By 1150 Arabic science was generally in decline. There did come to fruition, however, the line of development initiated in the ninth century A.D. by the Banū Mūsā, namely the Muslim application of Hellenistic mechanics. There was not much originality in theory, but there were ingenious and beautiful contrivances based upon the *Mechanics* of Hero of Alexandria and the *Pneumatics* of Philo of Byzantium. Great attention was paid to the determination of specific gravities, using the principle of Archimedes; to problems arising out of the use of the lever and balance; to clepsydras or water-clocks; to water-wheels; to fountains; and to various other automata. As early as 807, an elaborate water-clock had been presented to Charlemagne by the Caliph Hārūn ar-Rashīd. About the middle of the twelfth century, a clock was installed in the Bāb Jairūn at Damascus, and this clock became famous; Ibn as-Sā'ātī wrote a book about it in 1203. Just after the beginning of the thirteenth century there were written the two chief Arabic works on mechanics, namely the *Kitāb mīzān al-hikma* of Al-Khāzinī of Merv, and the *Kitāb fī ma'rifat al-hiyal al-handasīya* (*c.* A.D. 1205) of Al-Jazarī. The former dealt with the measurement of time, with the theory of the lever (continuing the work of Thābit ibn Qurra), with capillarity, and with gravity, which was supposed to be directed towards the centre of the universe and to affect the sea and the atmosphere; it gave also tables of specific gravities of liquids and solids. Al-Jazarī was more technological, treating mainly of clepsydras, fountains, and other contrivances operating on hydraulic principles. The glorious achievement of the 'Abbāsid caliphs such as Al-Ma'mūn (813–833) at Baghdād was emulated in the following century by the Umayyad dynasty in Spain, notably by Al-Ḥakam at Córdoba (961–976). Córdoba was 'the Jewel of the World' in the tenth century, the cultural focus of Europe, where one could walk for ten miles in a straight line by the light of the public lamps. Spanish Muslims, in particular Al-Zarqālī (*c.* 1029–87), made fine scientific instruments, including astrolabes. The astrolabe occupies a key position in medieval astronomy, and although a discussion of its merits is outside the scope of this article, it is indicative of the skill attained by the Muslim instrument makers, who were frequently physicists and astronomers as well. This skill was still being exercised in the observatory of Ulūgh Beg at Samarkand in 1437.

Outside optics and mechanics the medieval world achieved little in physics, the other branches of the subject not having been freed from various metaphysical speculations or generally reduced to mathematical expression. Jābir ibn Ḥayyān commented in the eighth or ninth century on the nature of magnetic force; and though the derivation of the magnetic compass may be Chinese, it was first widely used for navigational purposes by Muslims in medieval times, and is mentioned by Alexander Neckam, who died in 1217. Apart from the outstanding researches of Ibn al-Haitham, the general temper of physics was Aristotelian, as we find it in many of the Arabic encyclopaedic and philosophical works, such as those of Al-Kindī, Al-Fārābī, Ibn Rushd (Averroës), and Ibn Sīnā, and of the Brethren of Sincerity (Ikhwān aṣ-Ṣafā'). Aristotle's *Meteorologica* led to a 'meteorology' of wide generality, embracing what we should now define as meteorology together with perspective, which latter involved both physical and physiological optics. Large-scale natural phenomena, such as the tides, commanded attention, and many successful measurements were made in physical geography. The theory of the rainbow, especially, figures throughout Arabic physics from Al-Kindī to Ash-Shīrāzī, initially in terms of reflection on the basis of Aristotelian and Euclidean ideas, and finally incorporating the theory of refraction which derived from Ibn al-Haitham. Musical intervals were studied by Ibn Sīnā, who wrote about them in his *Kitāb ash-Shifā'*.

REFERENCES

[1] *Opticae Thesaurus Alhazeni Arabis libri septem* (Basel, 1572).

[2] NAZIF BEY, M. *Al-Ḥasan ibn al-Haitham* (2 vols., in Arabic) (Cairo, 1942–3).

[3] WINTER, H. J. J., and 'ARAFAT, W. *J. Asiat. Soc. Beng.*, **15**, 1–2, 1949.

[4] *De Crepusculis et Nubium Ascensionibus*, transl. Gerard of Cremona (Lisbon, 1542).

Heredity in pneumococci

HARRIETT EPHRUSSI-TAYLOR

The direct control of heredity, as opposed to selective breeding to maintain races in which desired characteristics are always present, has been one of the main goals of the practical geneticist. The discovery that a specific agent—a highly polymerized desoxyribonucleic acid—can transform one strain of pneumococcus into another with different serological characteristics is, therefore, most significant. This article discusses how far the discovery can be regarded as an example of direct control of hereditary character, and explains why it should not be taken as an instance of an effect of environment on genetic make-up.

Everyday experience demonstrates that hereditary mechanisms are conservative. Offspring tend to resemble parents very closely, and it is the gross deviation from this occurrence that surprises us. This is fortunate, for, were the hereditary constitutions of individuals readily affected by environmental factors, the perpetuation of species would be gravely endangered. In spite of this conservatism, gradual evolution of species continually takes place. To understand how both conservation and gradual evolution of species occur is one of the great problems of modern biology. Even more challenging is the problem of gaining control of heredity, to guide the evolution of species to the ends which man considers good.

The science of genetics has set out to explain the mechanisms of heredity and its variation. Geneticists now understand fairly well how the characteristics of diverse species of plants and animals are conserved. Oddly enough, the research which has culminated in the formulation of the laws and theories of modern genetics did not develop through the study of the constancy of species-characteristics so much as through the study of rare mutations in these characters. These mutations, often consisting of hereditary malformations, provided essential markers for the genetic material in individual organisms, and thus enabled the geneticist to study how this genetic material is passed on to offspring. Just as mutations have been of primary importance in the study of heredity in higher plants and animals, so they are now playing an important role in the development of the genetics of bacteria. The present article deals with a remarkable kind of mutation in bacteria, that of specifically induced transformations in *Pneumococci*. However, before turning to examine this phenomenon, let us touch first upon some of the essential points of modern theories of heredity.

In probably all cells there are to be found special structures which cannot arise *de novo*, and which are exactly "copied" during cell-multiplication to form the hereditary substratum of the new cell. If any part of these structures is lost, the cell cannot by itself replace it, for it is only when these elements are themselves present that their reproduction can take place. In addition to being responsible for their own reproduction, these elements initiate reactions which lead to the formation of structures and performance of functions. The hereditary substratum is composed of units which can be differentiated both by their specific physiological activities and by their localization in cell-structures. These units, called genes, have the dimensions of large molecules, and probably differ structurally from each other at the molecular level. While one can already see in these hereditary units the makings of a system which is conservative in function, its stability would not exist without mechanisms to assure each newly produced cell a complete set of genes. Such a mechanism is known to exist in higher plants and animals, where genes are aligned in long structures called chromosomes. The number of these thread-like structures, and their size, differ for each species, and are species-characteristics. Before cell division, the genetic material in the chromosomes is duplicated, and the chromosomes split longitudinally, so that each new thread contains at least one copy of each gene. During cell-division, each daughter cell receives one of the two threads formed from each chromosome of the reproducing cell.

The greatest genetic variability is found in organisms which reproduce sexually. This is so because in the course of sexual reproduction only one-half of the chromosomal material of each parent is utilized to form the fertilized egg. Thus the new individual draws upon two different individuals for its genetic material, and is composed

of only a part of the genetic patrimony of each partner. Since the new organism is not the simple sum of the total genetic material of each parent, and represents an assortment of only half of this material, new combinations of hereditary characters arise with each individual produced by a given pair of parents. At present, man cannot control which parts of the genetic material of sexually reproducing organisms will be passed on to their descendants. However, by following scientific breeding procedures, he can increase the incidence of desired properties in the offspring, or even produce true-breeding races in which the desired character is always present as long as matings are made according to strict rules.

While heredity as a whole operates to conserve the forms and functions of organisms within certain limits, new characteristics do appear from time to time. In the reproduction of every hereditary unit, or gene, there is a certain probability that the copying process will not be carried out exactly, and that a gene having new properties will appear. The probability is very small, and can be estimated only with difficulty. This spontaneous mutation of hereditary units provides a source of new kinds of hereditary material.

Since man cannot predetermine which genes are to be passed on to the offspring of sexually reproducing organisms, it has been stated that he has no control over heredity. The validity of this statement depends, of course, on what one means by control. It has been possible to create lines of plants and animals which breed true for certain desired characteristics, and it is thus clear that the hereditary substance of organisms can be manipulated for the purposes of mankind. However, one may have a very different kind of control in mind, and, indeed, this kind of control has been dreamed of by geneticists for many years. From various lines of biological research it seems likely that genes perform very specific operations in the organism. One can imagine that some day we shall be able to alter the gene specifically, to make it perform certain new desired functions. At present, there is no evidence that such control has ever been achieved. It has been possible by the use of X-rays and various other agents to increase —in a random fashion—the incidence of mutations, and this in turn has given a new degree of control over heredity. It has permitted man to increase the natural reservoir of variability inherent in genetic systems, thereby providing more new genes from which to select desirable ones. It falls short, however, of the imagined goal.

It is upon a background woven out of the efforts of geneticists to gain control over genetic systems that we should examine the nature of a rather recent discovery, viz. the transformation of pneumococcal types. At first sight, this phenomenon appears to offer the possibility of controlling the hereditary properties of an organism. It is proposed, consequently, to examine the essential aspects of the phenomenon, and then to discuss to what extent we are justified in supposing that we have at last attained the direct control of a hereditary character.

Virulent pneumococci synthesize polysaccharide capsules about themselves, which permit them to grow in their animal hosts unsuppressed by phagocytic destruction. The ability to synthesize a capsule is a constant hereditary trait. In nature, different races of pneumococci can be found, which differ from each other with respect to the chemical structure of the polysaccharide composing their capsules. The formation of a capsule of a given chemical structure is, again, constant in a given line, and therefore a hereditary trait. Distinctive kinds of antibody are formed against each type of capsular polysaccharide when the encapsulated bacteria are injected into animals. Consequently, by serological means, pneumococcal strains can be classified into groups. In a given group all races form the same kind of capsular polysaccharide, although the individual strains may differ with respect to other characters. The grouping or "typing" of pneumococci is arbitrary, but is based upon a very exact criterion.

From time to time mutation occurs in the capsule-forming mechanism, and there appear pneumococci which have a diminished power of capsule synthesis, or even a total loss of this capacity. From such mutants one may establish lines in which capsule synthesis is permanently diminished, or lines in which capsules are totally lacking. The mutated states are thus hereditary.

In 1928, Griffith discovered that unencapsulated pneumococci could be made to form capsules again, if they were injected into mice simultaneously with heat-killed encapsulated pneumococci. This discovery was particularly remarkable, since it was evident from Griffith's experiments that the induced capsule was identical with that formed by the heat-killed bacteria, and independent of the origin of the unencapsulated pneumococci in which the induction had occurred. Thus, an unencapsulated bacterium which had been derived from a Type II encapsulated race could be made to synthesize the capsule of a

Type III race, provided the induction was done in the presence of heat-killed Type III bacteria. From this basic observation the phenomenon has received its name of 'transformation of pneumococcal types.'

It seemed likely that this transformation was due to the presence of a specific agent in encapsulated bacteria. Study of the phenomenon was taken up in the laboratory of Avery, where it was found that the induction could be done with cell-free extracts of encapsulated pneumococci, acting *in vitro* upon cultures of unencapsulated pneumococci growing in a special medium. After eleven years of study of the inducing agent, Avery and his co-workers MacLeod and McCarty published the results of their research upon its chemical nature (1944). All chemical and biochemical evidence indicated that the transforming agent (TP) was probably a highly polymerized desoxyribonucleic acid. The publication of this result has roused much comment from both geneticists and chemists. From Griffith's experiments, geneticists had become interested in the transformation phenomenon, since it seemed that for the first time man was inducing a specific inheritable change in an organism. That the inducing substance should be a nucleic acid of the desoxyribose type excited still greater interest, for this is a substance which in higher plants and animals is known to occur only in the chromosomes. For many years, geneticists have speculated about the chemical nature of genes, and because proteins were known to have special structures and biological activities, it was supposed that the protein parts of the chromosomes were differentiated to give rise to gene-specificity. Before the studies on the pneumococcal TP were published, there had been no reason to believe that nucleic acid molecules in the chromosomes had a role in determining the specific properties of each gene. Chemists and biochemists were similarly interested by the studies on the TP of pneumococcus, since it had been supposed, on the basis of admittedly limited chemical evidence, that the desoxyribonucleates isolated from such different sources as wheat germ and calf thymus were chemically identical. If the transforming activity of the desoxyribonucleic acid extracts of encapsulated pneumococci is due entirely to their content of this substance, it follows necessarily that nucleic acids of the desoxyribose type must have diverse biological specificities, and hence must also have diverse chemical structures. This is evident from the experiments of McCarty and Avery (1946*a*), who isolated in purified form the desoxyribonucleates of three different types of encapsulated pneumococci. Each preparation induced unencapsulated pneumococci to form capsules, but each transformed the bacteria into a different type. The type of polysaccharide found in the induced capsule depended always upon the source of the transforming extract. Thus the kind of new synthetic activity acquired by the transformed bacteria was determined by the origin of the nucleic acid with which the induction was accomplished. It should be noted also that desoxyribonucleic acid of calf thymus is totally inactive as an inducing agent.

It is difficult to be certain that no other material in the desoxyribonucleic acid extracts contributes to their specific activity, for these extracts are active in trace amounts. However, extensive serological, chemical, and biochemical studies carried out by McCarty and Avery (1946), and by Hotchkiss (1948), indicate that no complex organic sustance other than desoxyribonucleic acid is detectable in these extracts. Furthermore, biological activity is destroyed by any agent which depolymerizes the nucleic acid. Thus, transforming activity is rapidly destroyed by crystalline desoxyribonuclease, a specific depolymerase, but is untouched by proteolytic enzymes or ribonuclease. Apparently, therefore, the polymerized desoxyribonucleic acid is solely responsible for the biological activity of the pneumococcal extracts.

As a biological agent, the capsular TP of pneumococcus presents some interesting features, since it has a dual action in the transformed bacterium. It induces both capsule formation and its own reproduction by the bacterium. Thus, once transformed, the bacterium passes a copy of the TP on to its progeny, and they, too, form capsules. The TP therefore possesses properties attributed to genes, in that genes also have this same dual role. We may, therefore, suppose that the capsular TP is simply a part of the genetic substratum of the encapsulated pneumococcus, which has been extracted in active form and introduced into the unencapsulated bacterium. Were this the case, we should expect to find other resemblances between the capsular TP and genes, and, as well, other gene-like agents in the desoxyribonucleic acid extracts.

Inside the bacterium, the capsular TP undergoes spontaneous mutations upon very rare occasions, much as genes do (MacLeod and Kraus, 1947; Taylor, 1949). These mutations give rise

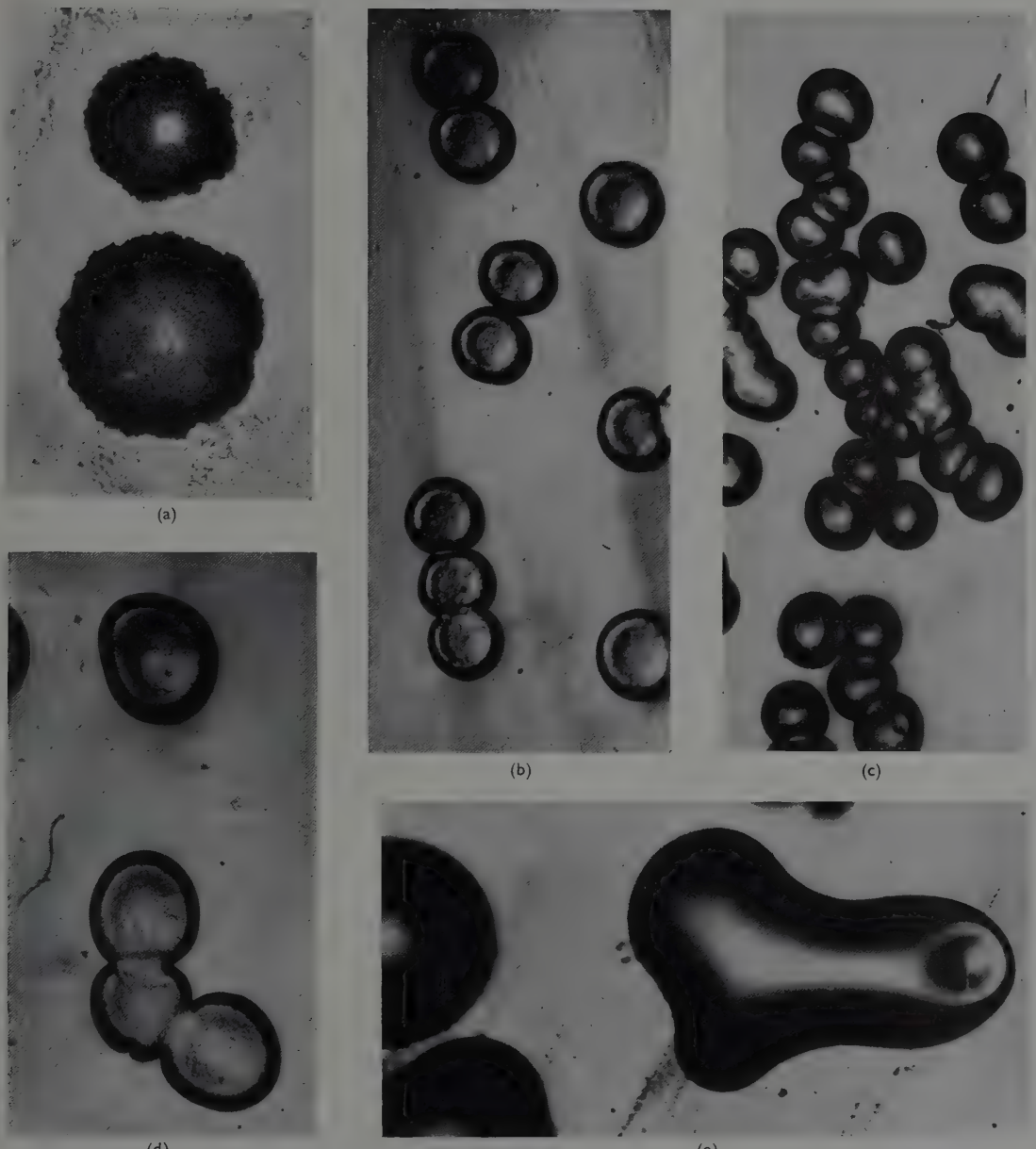


FIGURE 1 – *Photographs of colonies of strains of* Pneumococcus *grown on the surface of a solid medium.* (a) *Strain ER, an extremely rough colony. The bacteria are not encapsulated, and form long chains which become matted.* (b) *Strain R, rough colony. These also are unencapsulated, but do not form long chains.* (c) *Strain SIII–1, intermediate between rough and smooth. These bacteria form small amounts of Type III capsular polysaccharide. Reduced capsule formation is due to mutation of the capsular transforming agent.* (d) *Strain SIII–2, smooth colony. These bacteria are encapsulated, but also form less polysaccharide than does the normal SIII–N strain, owing to mutation of the capsular transforming agent in this race.* (e) *Strain SIII–N, smooth colony. Encapsulated with Type III polysaccharide.* (× 25)

to capsular transforming agents having modified biological activities (see figure 1). The mutated agents can be introduced into unencapsulated pneumococci by the transformation technique, where they induce the formation of modified capsules (see figure 2). The transformed pneumococci

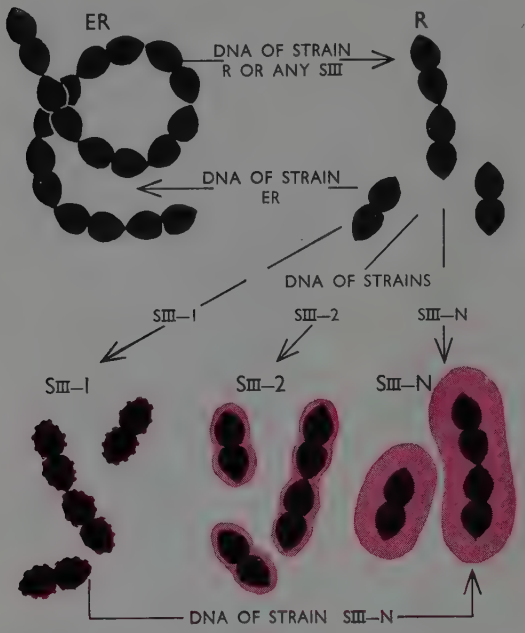


FIGURE 2 – *Diagram of some of the transformations which can be induced in the strains shown in figure* 1. *DNA = desoxyribonucleic acid fraction of the indicated strain. Red = Type III capsular polysaccharide. Note that the DNA fractions of the SIII strains have two different specific transforming activities: ER to R, and R to the SIII condition which corresponds to the source of DNA.*

copy the mutated agent faithfully and pass copies on to their progeny, just as occurs in the transformations with an unmutated capsular TP.

It has been found also that a given desoxyribonucleic acid extract has more than one kind of transforming activity. The desoxyribonucleate of Type III pneumococci, for example, contains at least two known kinds of transforming agents. One induces capsular polysaccharide formation in unencapsulated strains, and a second induces a distinctive morphological change in a particular strain of pneumococci (see figure 2).

In summary, it seems probable that the specific transforming agents are composed of desoxyribonucleic acids having different specific activities, and that they are parts of the genetic substrata of the bacteria from which they are isolated. In specific transformations, these agents become incorporated into the genetic constitution of the bacteria transformed, endowing them with both new genetic elements and new hereditary characters.

To what measure have these studies advanced our control of genetic systems? One should not conclude that we have finally acquired control over the biological properties of a genetic substance, for we have not yet influenced the properties of the gene-like transforming agents themselves, nor have we created a genetic element *de novo*. In pneumococcal transformations, a ready-made agent is taken from one bacterium and made to interact effectively with another, thereby endowing the transformed bacterium with new hereditary properties. Consequently, in one respect, these transformations resemble hybridizations, in that they are the manipulation of preformed genetic material. We may hope some day to be able to modify at will the properties of transforming agents, for these agents are easily accessible outside the cell and in solution in a test-tube. Perhaps, even, chemists will be able to explore the chemical structures of these agents sufficiently to permit the synthesis of gene-like agents from relatively simple organic molecules.

While there is every reason to believe that through a study of these transformations we shall gain much new insight into the structure and function of genetic determinants as a whole, there is, at present, no basis for supposing that the discovery of the transformation phenomenon represents a clean break with the concepts of modern genetics. Although these transformations are induced by agents which are introduced into the environment of growing bacteria, and can be called 'environmental agents,' the origin and properties of the transforming agents are such as to make one believe that we are concerned here with the introduction of new genetic material into the bacterium, and not with the modification by environmental factors of the hereditary substratum which the bacterium already possessed. The transforming agents which we isolate from various bacterial strains have their own unique properties, and for the moment their properties are as uncontrollable by man as those of the gene.

REFERENCES

[1] GRIFFITH, F. *J. Hyg. Camb.*, **35**, 23, 1935.
[2] AVERY, O. T., MACLEOD, C. M., and MCCARTY, M. *J. exp. Med.*, **79**, 137, 1944.
[3] MCCARTY, M., and AVERY, O. T. *Ibid.*, **83**, 89, 1946.
[4] *Idem. Ibid.*, **83**, 97, 1946*a*.
[5] HOTCHKISS, R. D. *Colloques du C.N.R.S.* (Paris, 1948).
[6] TAYLOR, H. E-. *J. exp. Med.*, **89**, 399, 1949.
[7] MACLEOD, C. M., and KRAUS, M. *Ibid.*, **86**, 439, 1947.

Polled cattle

JOHN HAMMOND

All English children love the nursery-rhyme featuring 'the cow with the crumpled horn,' but the unreflective man or woman may think it unimportant whether or not cattle have horns. Dr Hammond describes the history of polled or hornless cattle—which goes back to ancient Egypt of 2150 B.C.—and explains that for several reasons polled cattle are desirable. Horned cattle may be dehorned, as calves, by chemical means, but, during the last few decades, methods of breeding polled cattle have been successfully studied and adopted.

So far as is known from fossil remains, all primitive breeds and species of cattle were horned, although this is doubted by Arenander, who cites *Leptobos frazeri* and some other hornless types of the Pleistocene period in India, which have been described by Rütmeyer. It is generally believed that polled breeds arose as mutations or sports from horned varieties. Characters such as horns are inherited by means of chemical substances called genes, arranged in pairs on the chromosomes of the nucleus of the animal cell. Genes determine the formation of the character in the new individual. When, by chance, the chemical nature of a gene is changed (as it can be sometimes by X-rays and other means) it gives rise to a mutation or sport. Most of these mutations are recessive in inheritance, that is, the character in question disappears in the first generation of a cross with the normal primitive variety, and then reappears in the next generation in the proportion of 1 in 4. The polled character in cattle is an exception in this respect, however, for although it is a mutation from the primitive form it behaves as a dominant, that is, one which appears in the first generation of a cross with the primitive type, and which, in the second generation, appears in the ratio of 3 to 1; two of these three will not breed true to polled, although the other one does (figure 4).

HISTORICAL

In general the history of cattle follows the history of man. Wherever either primitive or modern man has migrated, he has tended to bring with him his own breeds of cattle. An account of the literature on the origin of hornless cattle has been given by Dechambre (1922). In this he states that the earliest records of polled cattle in civilized countries occur in Egypt about the year 2150 B.C. (figure 1). Polled cattle were also described by Herodotus (*History*, Book IV) in southern Russia (Scythia). Whether these had the same origin and were transferred from Egypt is not known for certain. There exist in Africa today some native polled breeds of cattle (figure 2) kept by tribes in French West Africa, which no doubt have arisen from the Egyptian polled cattle, for, as Curson and Thornton (1936) have shown, there was probably a migration of tribes from the north to south of Africa along definite routes.

The next earliest account of polled cattle occurs in Scandinavia (figure 3), where, in Sweden, polled cattle of a small red breed (*Rod Kullig*) and also a white breed (*Fjäll*) existed, as they do to this day. It is possible that these were derived from southern Russia, for similar breeds also exist around Archangel in Russia, and it is known that tribes from southern Russia migrated to Finland. There is the possibility, however, in the lack of absolute proof of the transport of southern Russian polled cattle to Scandinavia, that the Scandinavian polled cattle arose from a local mutation, for it is a well-known fact that the same mutation may arise at different times and places. There is indeed recent evidence (see below) that the polled mutation has occurred independently during recent times among pedigree horned cattle in the U.S.A. and in Britain.

It is highly probable that the majority of such polled mutations in horned breeds would not survive under primitive conditions, for the polled character would be a distinct disadvantage in combat with other bulls of the breed, when they fought for their herds or in defence against predatory animals. Moreover, polled breeds would not be favoured and retained by peoples who use cattle for draught purposes, since in many lands the horns are frequently used to catch the cattle or to yoke them to the plough or cart. Conversely, the places where the polled mutation would be likely to be retained were those in which there was little cultivation, and cattle were required for meat and milk purposes only. Thus it was that

FIGURE 1 – *A polled bull of ancient Egypt* (*Kronacher*, 1921).

polled cattle obtained a strong footing in Scandinavia, while few records of the development of polled breeds exist in central and southern Europe, Asia, and most of Africa.

The primitive cattle of Great Britain and Ireland were all horned, and Wilson (1910) has described how the various polled breeds of British cattle were derived mainly from red stock brought over from Scandinavia by the Vikings. In Ireland, the Maol, a polled breed almost extinct today, was produced. In Scotland, the imported polled cattle breeding with the primitive black horned cattle of the Celts gave rise to the polled black Aberdeen Angus (figure 5) and Galloway, while Viking settlements in East Anglia developed the Red Poll (figure 6), possibly from pure Scandinavian stock and later by crosses of this with red horned breeds. Here also, by crossing with the white horned cattle introduced into Britain by the Romans, they gave rise to the polled Park Cattle which exist today in a few places. When men from Britain began to colonize North America, Australia, New Zealand, and South Africa they took many animals of these polled breeds with them, so that now polled cattle are distributed over both the south and the north temperate zones of the world.

In addition, however, to the polled breeds which were derived directly from Britain, polled strains of horned British breeds have arisen by mutations in North America, and have been developed there and elsewhere as separate breeds. Such polled mutations in normally horned breeds have arisen from time to time in Great Britain also, but hitherto they have not been preserved, since tradition and breed-society rules did not allow of the admittance of such animals to the herdbooks. Duerst (1931) gives references to cases of the polled mutation occurring in many different breeds of horned cattle. Within the last three years, polled mutations in pedigree Guernsey cattle (one in England and one in U.S.A.), and at least one in Jersey cattle (in England), have been recorded. It has been stated that the chances of this occurring are about once in 50,000 births (Clover, 1948). In the home of a long-established horned breed such mutations stood little chance of survival. It was otherwise, however, in new countries where the survival depended on the value of the new mutations to the stockbreeder rather than on the traditions of the breed. It was for this reason that when polled mutations occurred in the Hereford and Beef Shorthorn breeds in the U.S.A. in comparatively recent times they were retained and bred from. Nine polled sports were listed by Spillman (1907); two of these Hereford bulls came from horned parents and were used by Boyd in establishing a pure race of polled Herefords.

In 1901, W. Gammon of Des Moines, Iowa, circularized members of the American Hereford Cattle Breeders' Association, asking for hornless sports. 14 were found, and Gammon bought 7 cows and 4 bulls. The polled bulls mated with horned Hereford cows gave 50 to 75 per cent. hornless calves. A national breed organization for these polled Herefords was started about 1907 with a membership of 5, and by 1948 the new registrations of polled Herefords (figure 7), reached about 30,000 a year.

Owing to the demand for a polled beef animal which was a good grazer, these polled Herefords were introduced into Australia and are now spreading rapidly there. In the U.S.A., the polled Beef Shorthorn has also been developed. It is said to have originated in the State of Ohio about 1870 from pure-bred Shorthorn stock, and also in Minneapolis in about 1882, when a pedigree roan cow with scurs (small loose horns) produced three hornless calves. An American polled Shorthorn herdbook society was formed in Chicago in 1889, and the first herdbook was published in 1898. The polled Shorthorn is finding a ready demand in beef-producing areas, and has spread to the Argentine, Australia, and South Africa.

ARTIFICIAL DEHORNING

In beef breeds kept under range conditions, polled cattle are favoured, except where predatory animals exist, since animals suffering from injuries due to their horning one another are difficult to treat. Moreover, the presence of horns

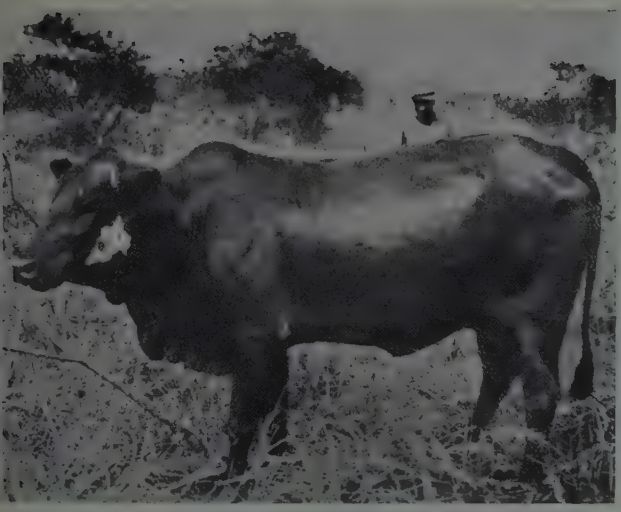


FIGURE 2 – *Kivu (Sanga) cow, polled (H. H. Curson and R. W. Thornton).*

FIGURE 3 – *Fjäll cow, Sweden (H. H. Curson and R. W. Thornton).*

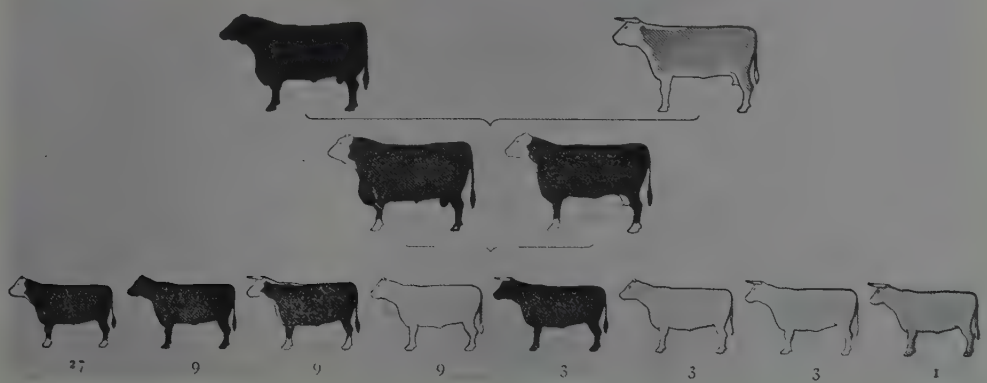


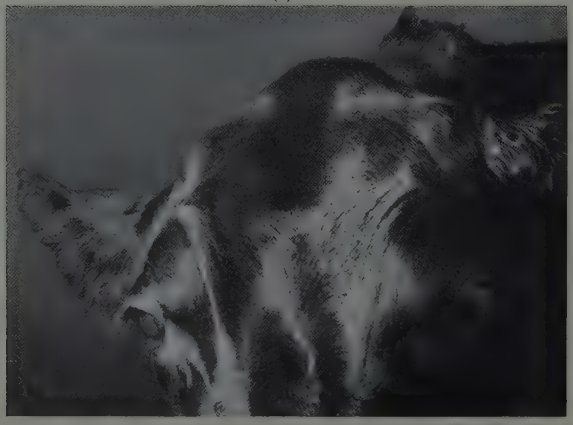
FIGURE 4 – *Diagram showing the character inheritance in cattle. The Aberdeen Angus has the black and polled characters which are dominant over the red and horned characters of the Hereford. The latter, on the other hand, has the white face pattern which is dominant over plain face. The three dominants appear in their progeny, but when these are interbred eight different types are possible, and the chances of each type appearing is indicated by the numbers beneath the animals.*

FIGURE 5 – *Aberdeen Angus cow* Julie Erica.

FIGURE 6 – *Red Poll heifer* Kirton Rueful Girl.

FIGURE 7 – *U.S.A. Polled Hereford Steer.*

(a)



(b)

(c)

FIGURE 8 – *Crossbred steers showing differences in horn development.*

(a) *'Scurs' or loose horn growth: first cross Shorthorn bull × Aberdeen Angus cow. Heterozygous for horns.*

(b) *'Lumps,' a small knob of bony growth from the skull but no horn growth: second cross Aberdeen Angus bull × (Shorthorn bull × Aberdeen Angus cow) cow. Probably heterozygous for the horned condition.*

(c) *Polled, no sign of any horn development either in the skin or bone: second cross Aberdeen Angus bull × (Aberdeen Angus bull × Shorthorn cow) cow. Probably homozygous for polled.*

is a frequent cause of bruises and spoilage in the carcass when the animals are rounded up to be put on rail to the abattoir, and more polled than horned cattle can be loaded in each rail wagon for transport. In most large beef-producing areas of the world (Argentine, Australia, New Zealand) the steers are therefore mostly polled or dehorned. This operation is best done by rubbing the horn core in the newly born calf with a stick of caustic potash. In extensive range areas, however, it requires a lot of labour to round up calves for this purpose, and under such conditions the young growing horns are often debudded with shears or sawn off, a rather cruel and bloody operation, at a later stage of life. No wonder, then, that polled breeds and strains are now extending in these areas. For intensive beef production under yard feeding conditions too, such as in Scotland and eastern England, polled cattle are favoured, for, by polling, trough space requirements are reduced and more cattle can be put in each yard; thus Irish store cattle sent to be fattened in eastern England are now all dehorned, for they fetch about £1 per head more there than do horned cattle.

As to dairy cattle, the modern system in most countries of using run-through milking sheds has necessitated the dehorning of the dairy cows. Before milking, the herd is usually run in to a confined space, and here, as well as in the rush to the milking bale to get milked, horns may cause injuries not only to the skin of the cow but also to the udder. Moreover, a dig in the ribs from another cow when going to be milked is not conducive to that placid state of mind which is necessary for the easy discharge of milk to the machine or milker. In dairy cattle there has not been the same urge to produce polled breeds, however, as there has been with beef cattle, because the process of dehorning is much easier where the calves are confined and reared by hand. For this purpose the caustic potash method, and an electric dehorner which burns round the periphery of the horn bud in the newly born calf, are mostly used. This is carried out in most dairying areas of the world where milking machines are in common use, such as in the U.S.A., Canada, New Zealand, and Australia, and the 'new look' is not now discriminated against in many shows in the U.S.A., the champion cow in the 1947 Dairy Congress Show being without horns.

PRODUCING POLLED BREEDS

Since dehorning involves much time and trouble, and employs labour which could better be devoted to other purposes, there is much to be said for producing new polled types of the horned breeds of cattle. To be set against this are the abolition of the primitive beauty of gracefully spreading or upturned horns, and loss to the cowboy of a means of casting or lassoing his steers, and, in some cases, of a means of rapid identification of cattle where numbers are branded on the horns. However, if new polled breeds were produced the stockman could always have the option of which strains—polled or horned—would suit his purpose best.

If it were desired, there are two ways in which a polled strain of a horned breed could be produced. The first is that of preserving the polled mutations which appear from time to time among animals of the pure horned breed—the way in which the polled Hereford (figure 7) has been produced. This could be encouraged by opening a polled section of the herdbook concerned, in which these animals and their progeny (with due precautions—see below) were entered.

The second method is that of crossing with a polled breed and then upgrading the resulting progeny to the pure breed concerned, as in the grading-up schemes which exist in all open herdbooks. This is the method which has been successful in producing the new sex-linked strains of different breeds of poultry in recent years. The polled Suffolk sheep, too, has been produced from crosses between the polled Southdown and horned Norfolk breeds, and now breeds true to the polled character. Some of the ancestors of the present Red Poll breed of cattle, which now breeds true for the polled character, were horned.

Both these methods are being used to develop polled types. Using the first method, that of collecting mutations which occur from time to time in the pure breed, the various breed societies fall into a graded series reflecting the attitude of the majority of their members. At the one extreme, even artificially dehorned animals are debarred from being registered as pure (Shorthorn and Hereford Societies of Great Britain); in other societies artificial dehorning is permissible although naturally-polled animals are not permitted (Friesian Society of Great Britain); while in several other societies (U.S.A. Holstein-Friesian, Guernsey and Jersey Societies) naturally-polled animals are admitted to the herdbook without any special note being made of the fact, or a special mark is made against the names of polled entries (U.S.A. Shorthorn and Ayrshire Societies). At the other extreme, the polled animals are registered in a

separate herdbook by a separate breed society which is concerned with breeding them true to this character (Polled Hereford Society of the U.S.A.).

Within some of those breed societies which at present prohibit the registration of polled mutations, a few members have broken away. They are attempting to produce polled types by cross-breeding with a suitable (similar commercial qualities and colour) polled breed and then grading-up back to the original breed; for, while the polled and horned characteristics are inherited as units without blending, the commercial qualities are inherited in a quantitative blending fashion. Thus, while in first crosses between the polled Red Poll and the horned Ayrshire all the offspring are polled, in general build and commercial qualities the first cross is intermediate between the two breeds. When these first-cross animals are back-crossed to the pure Ayrshire, the offspring have 75 per cent. of the build and commercial qualities of the Ayrshire, while 50 per cent. of them are horned and 50 per cent. are polled. If these polled animals are now mated back to the pure Ayrshire again, the offspring have 83½ per cent. of the build and commercial qualities of the Ayrshire type, and 50 per cent. of them are polled, and so on for each successive generation of grading-up (see table).

Generation	*Per cent. Polled*	*Per cent. Commercial Qualities and Build of Ayrshire*
1. First cross ..	100	50
2. Polled offspring mated to Ayrshire	50	75
3. *Ditto*	50	87½
4. *Ditto*	50	93¾
5. *Ditto*	50	97⅞

Since all our dairy breeds of cattle now have an open herdbook and allow grading-up, all that would be necessary to obtain polled types of breeds would be to admit polled animals as foundation cows—the rest would then follow automatically with the grading-up.

When a high percentage of the pure breed characters is present in the grades (when the animals would be admitted as pure-bred) the next problem arises, namely that of getting them to breed true for the polled character. This is done by mating bulls and cows of the polled grades together, when 1 in 3 of the polled offspring will breed true to this character. To obtain true breeding it is quickest and most economical to concentrate on the bull, and pick out the 1 in 3 of the polled bulls which will breed true. Some indication of whether they are likely to breed true or not can be found (in the bulls, but not in the cows) by the absence of scurs or knobs (lumps of bone on the skull in the position of the horns), as bulls which are heterozygous for horned (or not breeding true for polled) will have these (see figure 8). After selection of the bulls has been made on this basis, it is advisable to make quite certain by doing a progeny test on the bulls before they are used for pure breeding. The young bull is mated with some 5 to 10 horned cows, and if without exception all the offspring are polled then the bull will breed true, but if even only one horned calf is found among the offspring then the bull should be rejected for further pure breeding. By grading-up the polled cows with such progeny-tested bulls the chances of horned offspring appearing in the breed will be reduced to zero, and they will become true breeding for polled in the course of time.

The chances of any of the polled cows in the herd ever breeding any horned offspring (even when mated with a horned bull) is reduced in each generation bred in this way from a succession of proven bulls: thus only 1 out of 3 cows will throw horned offspring to a horned bull in the first generation, 1 out of 6 in the second generation, and 1 out of 12 in the third generation, and so on. Using our knowledge of the Mendelian laws of inheritance it should be possible to produce pure polled strains of any breed of cattle without losing the characteristics of the breed in question, if it is so wished.

REFERENCES

[1] Clover, C. *Guernsey Breed J.* (U.S.A.), Ap., 1177, 1948.

[2] Curson, H. H., and Thornton, R. W. *Onderstepoort J. Vet. Sci.*, 7, 613, 1936.

[3] Dechambre, P. *Traité de Zootechnie T.3 Les Bovins* (p. 266), Paris, 1922.

[4] Duerst, J. W. *Der Rinderzucht* (p. 348), Berlin, 1931.

[5] Spillman, W. J. *Proc. Soc. Prom. agric. Sci. N.Y.*, 28th Ann. Meeting, 115, 1907.

[6] Wilson, J. *The Evolution of British Cattle, and the Fashioning of Breeds*, London, 1910.

Earthquakes

ERNEST TILLOTSON

Movements of the earth's crust provide information not merely for the seismologist but for geologists, engineers, and prospectors. In recent years some microseisms, caused by general unrest of the ground, have been found to be caused by storms at sea, and their study has proved useful for weather-forecasting. Here, earthquake phenomena are discussed with special reference to the New Zealand earthquake of 1929 and the Mikawa earthquake of 1945.

Deep rumblings and minor earth tremors are by no means uncommon in the town of Murchison and in the Buller River Valley in the north-west part of the South Island of New Zealand. Nobody takes much notice of them. But on 17th June, 1929, Murchison was wrecked by a violent earthquake [1]. In many places, the hills and the surrounding fertile flats were stripped to the bare rock, and great fissures were formed. The river Matakitaki ceased to flow below a newly formed lake which accumulated behind a dam of earth, rock, and *débris* piled up by the earthquake. Dams also appeared, with lakes behind them, across the Matiri, Maruia, and Buller rivers. Landslides made many roads impassable. Seventeen people lost their lives. Had the area north of Murchison been densely peopled there is no doubt that there would have been a heavy loss of life.

Elastic waves initiated in the focal region of the earthquake travelled through the body of the earth, and were received on sensitive seismographs at observatories throughout the world. Figure 1 shows the seismogram obtained on the Milne-Shaw instrument at the Royal Observatory, Edinburgh. A study of such records indicates that the depth of focus (i.e. the initial point of rupture) was normal, probably 18 kilometres—though a rather deeper focus was at one time suggested [2]. The release of what appears to have been compressional energy, probably by faulting at this depth, caused movement in the surface faults.

During the later Tertiary period in geological history the region appears to have been dry land, which the great crustal deformation of the late Pliocene broke into blocks differentially elevated, tilted, warped, and rotated. The breaking of the rocks near White Creek, 7 miles west of Murchison, and the uplift of the country east of it by some 16 feet, together with an average movement of the ground east of the fault of 9·4 feet north, showed renewed relative movement of the block. Figures 3, 4, and 5 show the surface effects, and the above brief description of this important earthquake brings out some general features of earthquakes which will be considered in rather more detail and with other examples.

NON-INSTRUMENTAL EVIDENCE

The intensity of earthquake violence in any particular place can often be estimated by its effects. The correlation of these effects with a particular number depends upon the scale in use, and upon critical estimation by an experienced observer. The Rossi-Forel scale and the Davison scale had wide use, but these have largely been supplanted by the Modified Mercalli intensity scale of 1931; this is an adaptation to present-day conditions of Sieberg's Mercalli-Cancani scale. The M.M. scale of 1931 divides macroseismic phenomena into 12 degrees, from 'not felt' to 'damage total,' and in this scale there is an attempt to make the divisions equal and precise [3].

When the intensity at several places has been assessed, it is possible on a map to draw lines of equal intensity, called isoseismal lines, and thus to estimate the area of greatest intensity of the earthquake. This does not necessarily coincide with the epicentral area (i.e. the point on the earth's surface immediately above the focus) as determined by instrumental observations, on account of geological surface structure, though the two are not often far distant. Unconsolidated deposits show relatively greater macroseismic intensity than does firm, consolidated rock.

If the epicentre is at sea, some information can be obtained concerning it by timing the arrival of the seismic sea wave at various points in its path.

INSTRUMENTAL EVIDENCE

Seismographs are instruments designed to record the passage of elastic earth waves. The

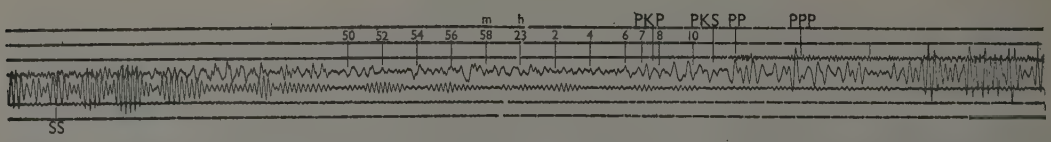


FIGURE 1 – *Seismogram from apparatus at the Royal Observatory, Edinburgh, recording the New Zealand earthquake of* 1929.
PKP *is a direct compressional wave through the earth's core.*
PKS *is a compressional body wave through the earth's core transformed to a transverse wave for the last part of its journey.*
PP *is a once-reflected longitudinal wave.*
PPP *is a twice-reflected longitudinal wave.*
SS *is a once-reflected transverse wave.*

essential idea is that a heavy mass, forming part of a dynamical system, is set in motion by the earth waves relative to its support and to the recording mechanism. Most seismographs employ a horizontal pendulum. If the axis of rotation of a pendulum is gradually changed from the horizontal to the vertical position, the effective part of gravity in controlling the rotation about that axis becomes progressively less. When the axis is almost vertical the pendulum, then nearly horizontal, is approaching instability and a long period of vibration becomes possible. A great static sensitiveness can be obtained, but heavy damping is required to diminish the effect of the free motion of the pendulum. A large magnification of the small earth motions is essential, and it is on the methods employed for magnification and damping that the efficiency of a seismograph depends.

Two horizontal seismographs are usually employed to measure the horizontal displacements in two perpendicular directions and to determine the azimuth of the epicentre. To measure the vertical movement of the ground it is usual to employ a horizontal pendulum, supported at a point between the axis and the weight by a vertical helical spring. A long period combined with stability is more difficult to obtain with a vertical than with a horizontal seismograph.

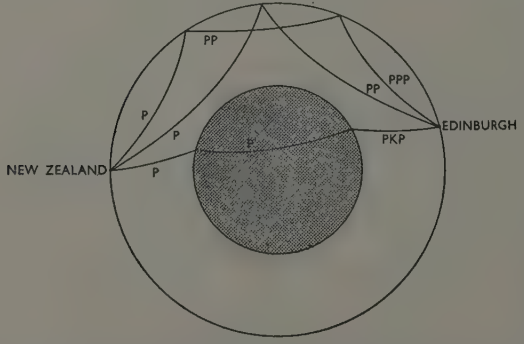


FIGURE 2 – *Section through the earth, showing the paths of some of the waves resulting from the New Zealand earthquake of* 1929. *Lettering as in figure* 1.

The most sensitive and efficient seismographs are probably those of the Galitzin type, both horizontal and vertical, which employ electromagnetic damping up to the limit of aperiodicity. Increased magnification is obtained by the use of electromagnetic recording. The Wiechert horizontal seismograph employs a very large mass (about 1000 kg) supported as an inverted pendulum by flat Cardan springs, stability being obtained by small horizontal controlling springs. Variable air damping is used, and both components are measured with the one instrument. The Milne-Shaw horizontal seismograph is a simple horizontal pendulum, using a small mass, a long light arm to give magnification, and photographic recording. If the damping is inadequate, the records are affected by the natural periodicity of the pendulum.

The seismogram obtained at the Royal Observatory, Edinburgh, for the Buller, N.Z., earthquake of 1929 (figure 1) shows several waves quite clearly. The interpretation is placed next to the trace. *PKP* is the most direct compressional wave which has come through the earth's core. *PKS* is a similar wave transformed to a transverse wave for the last part of its journey. *PP* is a longitudinal wave, once reflected at the earth's surface, while *PPP* is a similar wave twice reflected. *SS* is a transverse wave once reflected at the earth's surface. Figure 2 shows the paths of some of these waves through a section of the earth. The S-waves follow similar paths in the part outside the core. The remainder of the seismogram consists of multiple reflections, and waves which have travelled along the surface of the earth. Seismological observatories throughout the world prepare bulletins of their interpretations, which are sent to the International Seismological Summary Office, now at Kew Observatory. Here they are collated, and earthquake foci and times of origin are

FIGURE 3 – *Damaged bridge span resulting from the Buller earthquake of June* 1929.

FIGURE 4 – *Slip, three miles south of Murchison, showing wrecked house. (Buller earthquake, June* 1929.)

FIGURE 5 – *Bent railway lines near Westport. (Buller earthquake, June* 1929.)

FIGURE 6 – *Fault displacement at the surface, cutting across river terraces. (Buller earthquake, June* 1929.)

(Figures 3–8 are reproduced by courtesy of the Dominion Observatory, Wellington, New Zealand.)

FIGURE 7 – *Roman Catholic Seminary, Greenmeadows, New Zealand, showing damage. (Near epicentre of earthquake of February* 1931.)

FIGURE 8 – *Dr Moore's Hospital at Napier, New Zealand, tilted and destroyed by the February* 1931 *earthquake.*

FIGURE 9 – *Fukôzu fault crossing a paddy field. (Mikawa earthquake, January* 1945.) *See also figures* 11–13. *(By courtesy of Dr Hiromichi Tsuya.)*

FIGURE 10 – *Fukôzu fault line, showing damage to Shinto shrine. (Mikawa earthquake, January* 1945.) *See also figures* 11 *and* 14. *(By courtesy of Dr Hiromichi Tsuya.)*

determined. Since this work is at present some eleven years behind earthquake occurrence, useful preliminary calculations on foci and origin-times are carried out and published by (1) The United States Coast and Geodetic Survey, Washington, D.C., (2) The International Seismological Bureau, Strasbourg, and (3) The Jesuit Seismological Central Station, Saint Louis, U.S.A. The first normally reports within days and the other two within a few weeks of the occurrence of the shock.

All these stations provide most valuable data for the research worker interested in the deep structure of the earth, with its various discontinuities, the roots of mountains, and continental and oceanic structure. Instrumental timekeeping and recording at many observatories throughout the world are so good that it has become worth while to examine the seismological implications of aeolotropy (discontinuity of properties) in continental structure [4].

EARTHQUAKE GEOGRAPHY

When the epicentres of all well-authenticated earthquakes, whenever they occurred, are plotted on a world map, most of them are found to lie in zones associated with Tertiary or recent mountain-building. Certain other areas are found to be almost free from earthquakes. Since earthquakes are known to recur in approximately the same epicentral areas, it becomes important to know where these zones are, so that the seismicity of any area in the world may be assessed.

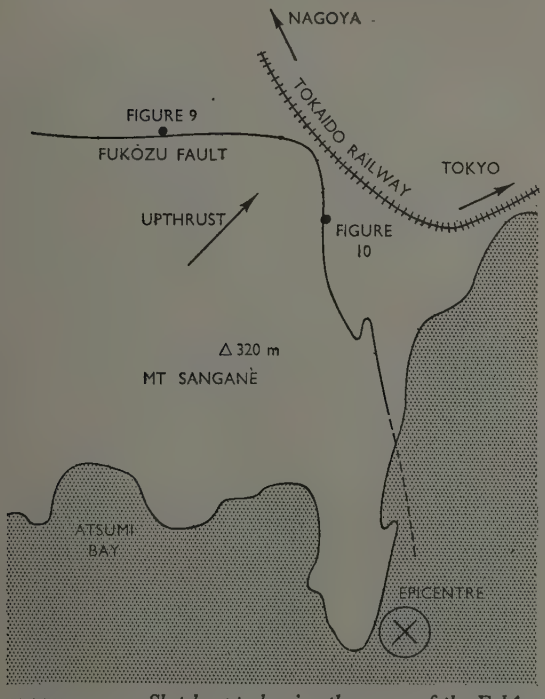


FIGURE 11 – *Sketch map showing the course of the Fukôzu fault (see figures 9 and 10), which became evident after the Mikawa earthquake of 13th January, 1945. (Scale 1 : 90,000 approx.)*

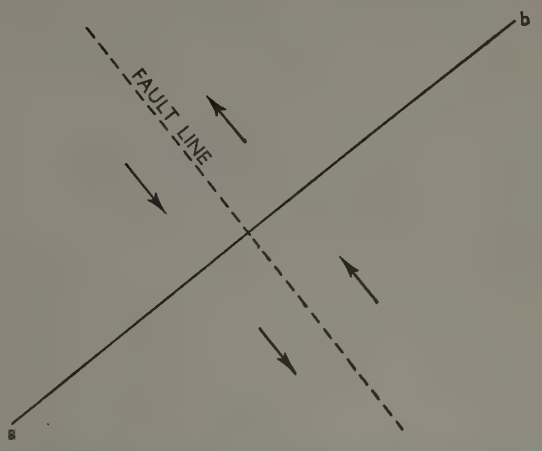


FIGURE 12 – *Ground plan to illustrate figures 9 and 13. Horizontal movement of 1·3 metres along Fukôzu fault due to Mikawa earthquake of 13th January, 1945.*

Earthquakes occur most frequently in those regions of the earth's surface where geological evidence shows that slow secular movements of the crust are still in progress, as in the Himalayas and the western coastal regions of America, or along the steeper flexures in the earth's surface, such as Japan, where there are high mountains in close proximity to great ocean depths.

One zone of earthquake activity apparently completely surrounds the Pacific Ocean, though possibly it does not include the Antarctic. The mid-Atlantic ridge is a seismic zone, and sends off a branch at right angles to itself through the Mediterranean Sea and Turkey to the Pamir Mountains, where the zone divides. The strongest branch runs along the Himalaya Mountains to Thailand and thence by way of Indonesia to the circum-Pacific belt. Another branch goes into mid-China.

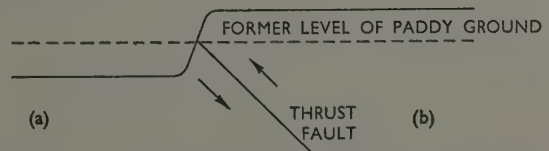


FIGURE 13 – *Vertical section to illustrate figures 9 and 12. Vertical movement of 2 metres along Fukôzu fault due to Mikawa earthquake of 13th January, 1945.*

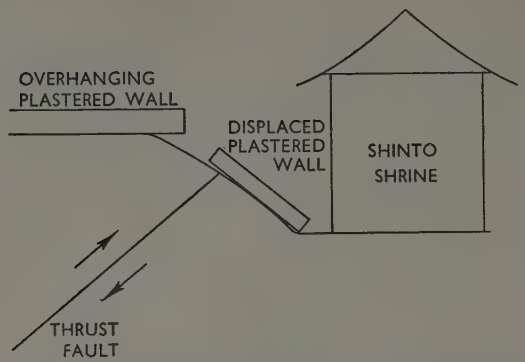


FIGURE 14 – *Vertical section to illustrate figure* 10, *showing damage to buildings along Fukôzu fault. Mikawa earthquake of* 13*th January,* 1945.

It must not be thought that all earthquakes have the same magnitude and depth of focus. Formulae for the calculation of magnitudes from instrumental recordings have been given by Gutenberg [5, 6], and it is considered that the same forces which cause earthquakes with surface foci also cause those which have the deepest known foci.

It appears probable, therefore, that faulting occurs at this great depth in the earth. Faulting at depth naturally causes permanent displacements at the earth's surface, where further faulting often consequently takes place. Figure 6 shows fault displacement occasioned by the Buller, N.Z., earthquake of June 1929; it will be seen how the fault cuts across river terraces.

I am indebted to Dr Hiromichi Tsuya for details of the remarkable Fukôzu fault which formed during the Mikawa earthquake of 13th January, 1945 [7]. This earthquake was one of the five most destructive Japanese earthquakes since 1943; it had an epicentre about latitude 34° N, longitude 137° E, near Atsumi Bay, west-south-west of Tokyo. It caused the deaths of 1961 people and injured many more. It totally destroyed 5539 houses and damaged over twice that number. The remarkable thing about the 9 km-long Fukôzu fault is that it turns almost 90° in plan in its middle course (see figure 11). Moreover, the fault line has an S-bend in one limb.

The fault itself is a reverse fault or thrust with the south-west side raised relatively to the north-east by vertical displacement of 2 metres. The horizontal displacement is much less and at most amounts to only 1 metre. The appearance of the fault varies with the nature of the surface rocks. In hard ground it usually forms steep overhanging cliffs, whereas in loose soil it appears either as a simple flexure of the ground or as a crumpled down-slope. The plane of the fault dips 50–70° to the south in the north wing and to the west in the south wing. It is probably not a new fault geologically; the northern wing separates structurally different parts of the upper Palaeozoic metamorphics (mica-schist and quartz-schist on both sides); the southern wing passes between metamorphics on the west and more or less schistose hornblende-biotite-granite on the east. There can thus be little doubt that the earthquake fault has been formed by accentuated and renewed crust movements along the pre-existing geological faults.

The area of earthquake damage to buildings was almost confined to the south-west side, except for a narrow zone along the fault. The Tokaidô railway line suffered no damage from the earthquake, although it is only 150 metres distant on the north-east side of the fault at Fukôzu. Accordingly, from this and other evidence it may be fairly inferred that, at the very moment of the earthquake, the Sangané-san mountain block, bounded by the fault on its northern and eastern sides,was up-thrusted forward in a north-easterly direction (figures 9, 10, and 12–14).

THE CAUSE OF EARTHQUAKES

The fundamental cause of earthquakes lies in the deep interior of the earth, and is probably connected with adjustments necessitated by the transference of heat. This heat may be original heat, radioactive heat, or heat due to chemical, frictional, or other causes. The interior adjustment calls for movement in the solid exterior involving compression-tension or shearing forces, or both, and this goes on until the elastic limit of the rock is reached, when rupture occurs. This rupture has occurred in the past at depths as much as 720 kilometres from the earth's surface, but not below that level. The initial point of rupture is at the present time considered to be the earthquake focus, and elastic waves appear to spread outwards in all directions from that point.

The point on the earth's surface immediately above the focus is known as the epicentre of the earthquake. The elastic waves radiated from the earthquake focus disturb, either temporarily or permanently, the equilibrium of the rocks through which they pass, and may initiate the adjustment of surface blocks to the new underground conditions. This results in surface faulting. Gravity anomalies, and active ground tilt, as measured by tiltmeters, may indicate potential or increasing

deep-seated stresses portending possible future earthquakes.

ENGINEERING CONSIDERATIONS

The damage caused by earthquakes to buildings, bridges, and so forth, calls attention to the need for studying the construction of earthquake-resistant structures. Something may be learned from photographs of earthquake damage as shown in figures 7 and 8, of the Hawke's Bay, New Zealand, earthquake of February 1931. It appears preferable, however, to get an idea of the nature of the forces involved, and then to design from first principles a structure to withstand such forces. The data needed include the accelerations —from which forces may be obtained by applying Newton's second law of motion; velocities—from which to determine momenta and kinetic energy; the displacements—for stability considerations; and the periods of the earthquake motion—for considerations of resonance.

Over forty accelerographs have been set up by the United States Coast and Geodetic Survey, well distributed in regions subject to earthquakes on the western side of America. An accelerograph is so called because its natural period of 0·1 second is relatively short compared to that of the principal earthquake waves causing damage. Probably the best accelerograph record so far obtained is that of the Imperial Valley earthquake of 18th May, 1940, obtained at El Centro, within 7 miles of a place where there was a fault-displacement of 12 feet due to the earthquake. By integration of this record the velocities and displacements were obtained [8], and it has been found possible to reproduce these movements satisfactorily on a shaking table.

Generally speaking, well-tied, single-storey buildings constructed of good materials, and with natural periods of vibration that do not coincide with those of the principal earthquake waves which cause destruction, have been found to serve best in areas subject to earthquakes, unless other conditions preclude such construction.

In many towns and cities in earthquake zones, where financial considerations might incline individuals to neglect earthquake-proof construction, building codes have been formulated by the city authorities, and, additionally, insurance companies likely to be concerned with coverage of this kind have their own minimum conditions [9, 10].

There are, finally, two aspects of general seismology which demand mention, and which now have their own literature. The first is seismic prospecting, in which explosions in the ground are made to send primary and other earthquake waves through the ground, whence they are received on specially constructed seismographs. The interpretation of the seismograms so obtained, assisted by geological extrapolation, enables the prospector to delineate underground structure and so save much in drilling-costs. The method has been found successful where superimposed strata have very different elastic properties, and in particular in oilfields in the Near East, of the U.S.A., Mexico, and Great Britain (Nottinghamshire). The second aspect is that of microseisms. These are not caused by earthquakes, but are general ground-unrest due to a variety of causes. The dominant ones picked up by seismographs of 3 to 7 or 8 seconds period have been found to be caused by storms at sea. The path of the storm centre, or point of origin of the microseisms, can be traced by the use of the tripartite seismograph station, and thus the seismograph serves as a meteorological instrument. This has been found extremely useful in the Caribbean Sea and elsewhere [11, 12] for weather-forecasting for marine and aviation purposes, and for tracking and timing the approach of hurricanes.

REFERENCES

[1] HENDERSON, J. *N.Z. J. Sci. Tech.*, **19**, No. 2, 65–144, 1937.

[2] BASTINGS, L. *Dominion Observatory, Wellington, New Zealand Bulletin*, No. 86, 1933.

[3] WOOD, HARRY O., and NEUMANN, FRANK. *Bull. seism. Soc. Amer.*, **21**, 277–83, 1931.

[4] STONELEY, R. *Mon. Not. R. astr. Soc. geophys. Suppl.*, **5**, No. 8, 1949.

[5] GUTENBERG, B. *Bull. seism. Soc. Amer.*, **35**, 57, 1945.

[6] *Idem. Ibid.*, **35**, 117, 1945.

[7] TSUYA, HIROMICHI. *Bull. Earthq. Res. Inst. Tokyo*, **xxiv**, pts. 1–4, 59–75, 1946 (together with a private letter).

[8] NEUMANN, FRANK. 'Analysis of the El Centro Accelerograph Record of the Imperial Valley Earthquake of May 18, 1940,' MSS. 9. Dept. of Commerce. U.S. Coast and Geodetic Survey, Washington, D.C., 1941.

[9] FREEMAN, J. R. *Earthquake Damage and Earthquake Insurance*, McGraw Hill (London, 1932).

[10] TILLOTSON, E. *Nature*, **144**, 297, 1939.

[11] DEACON, G. E. R. *Ibid.*, **160**, 419, 1947.

[12] TILLOTSON, E. *Ibid.*, **160**, 321, 1947.

The reactivity of free radicals in solution

H. W. MELVILLE

The idea that free radicals can exist is now familiar and well established, but the earliest known examples, such as triphenyl, are relatively unreactive, and the reactions they can bring about are limited. That radicals play a part in gas phase reactions has been known for many years, but only recently has the quantitative behaviour of radicals in solution been studied. Professor Melville, who has carried out much work on the subject, describes some of the results obtained. They are likely to lead to more precise theories of organic reactions.

It seems to be an established fact that as more and more non-ionic reactions are studied, both in the liquid and in the gas phase, their mechanism proves to involve free atoms or radicals. The general reason appears to be that this mechanism is an energetically economical way to accomplish a given kind of transformation. For example, consider the oxidation of an aldehyde (R.CHO) to a per-acid (R.COOOH). The simplest possible way for this to occur is by adding a molecule of oxygen directly to the aldehyde. No doubt each molecule would need to acquire a considerable amount of energy for this transformation, but that can always be done by the collisional processes existing in any system in which energy is distributed according to Maxwell's law. This kind of reaction would be bimolecular, and the rate would be proportional to the concentration of the aldehyde and of the oxygen. Furthermore, the rate would not be affected by environment nor by the presence of other kinds of molecules. In actual fact, the rate is independent of oxygen concentration, and it can be reduced to very small values by the addition of comparatively small amounts of oxidizable bodies like quinol. These facts can be explained only if we assume that by some mechanism a hydrogen atom is abstracted from the aldehyde, thus: $R.CH{:}O \rightarrow R.\dot{C}{:}O$. Then oxygen, being itself really a bi-radical, at once adds on to the aldehyde

$$O—\dot{O}—$$

radical: $R.\dot{C} : O$. This peroxide radical then removes a hydrogen atom from another aldehyde molecule, thus forming the per-acid R.COOOH and regenerating the aldehyde radical. The process does not continue indefinitely, but comes to a stop when two peroxide radicals react with each other.

Many other examples have been studied, and overwhelming evidence has been brought together in support of the existence of radicals in solution. The question that is now being actively considered is how to determine the nature and concentration of the radicals involved, so that the problem of measuring the rate of interaction of radicals with molecules and other radicals may be solved quantitatively. If this can be done, then a new chemistry of radical reactions will arise, and the further question of relating radical reactivity to chemical structure and environment will offer much scope for a better understanding of the nature of chemical reactivity as a whole.

DETERMINATION OF RADICAL CONCENTRATIONS

The radicals concerned in oxidation, in the addition-polymerization of ethylenic derivatives, and in the addition of hydrogen bromide, carbon tetrachloride, etc., to olefines are very reactive, and their concentrations must be relatively minute. Thus no direct physical method (such as the measurement of paramagnetism) is likely to be sensitive enough to demonstrate their existence. On the other hand, when the reaction is going steadily the rate of formation of radicals is equal to their rate of destruction. If I is the rate of formation, by whatever mechanism, and $k_t(P)^2$ is their rate of interaction, k_t being simply a bimolecular coefficient, then $I = k_t(P)^2$ and $(P) = (I/k_t)^{\frac{1}{2}}$. Thus to solve the difficulty it is necessary to devise some means of counting the number of radicals produced, and also some means of observing the rate at which radicals react with each other and therefore disappear. The first part of this problem has been under review for many years; the second part has not been solved accurately until comparatively recently.

Probably the most direct way of getting information about the rate of production of radicals is to suppress the reaction altogether by the addition of a powerful inhibitor. This can be done in the polymerization of various derivatives of ethylene such as vinyl acetate ($CH_2{=}CH.O.COCH_3$), where

benzoquinone will act in this fashion. When the inhibitor is removed, the reaction proceeds at a speed precisely identical with that of the normal reaction. This simply means that the quinone reacts with all radicals formed but does not affect their rate of formation.

An alternative method consists in retarding the reaction; for example, the oxidation of aliphatic aldehydes is retarded by quinol, which is again chemically destroyed. In this case the radicals, probably R—OO—, interact with the quinol instead of with each other. Thus for each radical initially generated one molecule of quinol is destroyed.

A third method, which is applicable only to polymerization reactions, consists in measuring the number of polymer molecules produced, assuming each polymer molecule to be the result of the addition of a radical to the monomer, which in turn forms a new radical, and polymerization then continues:

$R + CH_2{=}CHX \rightarrow R{-}CH_2{-}CHX{-}$, etc.

The problem of measuring the rate of combination of radicals is much more difficult. If the source of radicals is quite suddenly cut off, the radical concentration will at once start to diminish, and any reaction that these radicals may induce in the system will diminish proportionately with it. Fortunately, this can readily be achieved, if the radicals are produced photochemically, by the sudden discontinuance of irradiation. The experimental difficulty is then to observe the decrease in rates of reaction over relatively short intervals of time, because the radicals are short-lived in character. Until recently, this could not be done directly, but an older method has proved useful in this connection [1]. It consists in using intermittent radiation, the period between flashes being variable, but accurately measurable. Qualitatively, the principle is as follows. If a flash of radiation is absorbed by a system a certain concentration of radicals will be built up. In the dark period this concentration will decay. But if another flash of light impinges on the system before the concentration of the first crop of radicals falls to zero, then the second crop of radicals will by their presence accelerate the removal of the first lot by interacting rapidly with them. This effect will depend on the time-interval between the flashes. The result is that the speed of the reaction will be a function of the interval between flashes. By working out the theory of the method exactly, it becomes possible to calculate the life-time of the radicals under the conditions of steady illumination [2]. The average life-time of a radical, however, is equal to $(P)/k_t(P)^2$, i.e. the ratio of the concentration to the rate of removal. But $k_t(P)^2 = I$, and thus (P) can be calculated.

These life-times have turned out to be a good deal longer than was originally expected. In the gas phase it is rare to find simple aliphatic radicals lasting for more than 10^{-3} second, but in some polymerization reactions, such as that of styrene ($CH_2{=}CH.C_6H_5$), under favourable circumstances radical life-times of the order of 10^2 seconds have been observed. These much longer life-times make it practicable to observe directly the decay of chemical reactivity after the photo-exciting radiation has been cut off, provided sufficiently small amounts of reaction can be measured [3]. For example, in polymerization reactions there is a volume decrease of 10–20 per cent. By using sufficiently sensitive dilatometers the accumulation of 1 part in 10^7 of polymer can be detected, and thereby the decay of radical concentration can easily be measured directly over the periods of a minute or more. Similarly, the polymer molecules formed in the decay contribute to the viscosity of the system, and since viscosity is very sensitive to the addition of small amounts of polymer, the increase in viscosity can be used to observe the decay of radical concentration [4]. Radical concentration may also be measured by observing, with the help of very sensitive instruments, changes in the refractivity of a liquid or in the dielectric constant at high frequencies (100 megacycles/second). The radical concentrations produced in polymerization systems are never large; 10^{-8} to 10^{-10} mole/litre is a common range, the concentration of the monomer being of the order of 10 moles/litre.

The evolution and development of these new methods of analysing the mechanism of reactions throw open a wide field of inquiry, and thus provide a wealth of information about radical behaviour which could not possibly be obtained by any normal method of approach. Perhaps the simplest question is the way in which radicals react with each other. In particular, with polymerization reactions one of the first problems is whether the rate varies with the size of the polymer radical. It is a relatively easy matter to change the size of a radical, but the surprising result is that reactivity is practically independent of size, e.g. for vinyl acetate radicals $-(CH_2{-}CH.O.COCH_3)_n{-}$ an increase in the number of monomer units in the radical from 176 to 352 results in only a slight decrease of the bimolecular velocity coefficient for

interaction—from $3{\cdot}1 \times 10^9$ litres moles^{-1} sec^{-1} to $2{\cdot}5 \times 10^9$ [2]. This is not altogether unexpected, for it is known that such radicals are well extended in solution, and, further, that the chain of atoms has very considerable flexibility, owing to more or less free rotation of groups around the single bonds forming the backbone of the radical. The end of the radical thus possesses a high mobility, and should behave almost like a small isolated radical. The analogy cannot be carried too far, for if the medium is allowed to become viscous the speed at which radicals interact is materially cut down, because of their decreased mobility. Presumably, therefore, in an almost solid medium this life-time could become exceptionally large; there is recent evidence to that effect. If, however, we return to the analogy of small radicals, it is worth while considering how fast such radicals could interact, assuming that no energy is required for the occurrence of reaction. If reaction rates are expressed in terms of moles, litres, and seconds, the maximum possible value of the bimolecular coefficient is 10^{11}. In table I some interaction coefficients are shown for a variety of monomers. In every case the values are very much less than 10^{11}. This is not surprising, because it will not be an easy matter for the radicals to become oriented in such a fashion that chemical interaction can take place. The unusual feature is that the reactivities vary so much among the series. It points to the fact that chemical structure must have an important bearing on a relatively simple kind of reaction. On the other hand, if we turn to oxidation reactions in which the radicals involved are of the type RO_2, we find a more normal value for the interaction constant—but now the nature of the group R has no important effect on reactivity.

Chemically, the production and destruction of radicals is relatively unimportant except in so far as the control of rate of reaction is concerned. When a radical interacts with a monomer the action is one of addition, e.g.

$$R{-}CH_2{-}\dot{C}HX + CH_2{=}CHX \rightarrow R{-}CH_2{-}CH{-}CH_2{-}\dot{C}HX{-},$$

and the radical is reproduced. This cycle of events may occur 10,000 times. Similarly, in oxidation reactions the reaction of the RO_2 with the RH compound being oxidized does not result in destruction. Thus the rate of overall reaction can be very simply expressed as the rate at which radicals will use up monomer on the one hand and RH molecules on the other, or, put more compactly, $Rate = k(P)(M)$, where k is another simple bimolecular coefficient characteristic of the radical-molecule reaction under investigation, i.e. a numerical value of reactivity. Since (P) is now known, k can be calculated. As with the radical reactions, the maximum value of k would again be 10^{11}, but the actual values in table II are for a variety of polymer systems very much smaller. There are two reasons for this behaviour. These reactions do not occur without energy of activation, even though radicals are involved. This energy is due to the repulsion that a radical experiences in approaching the monomer for the act of addition. It can be evaluated; the figures are given in column 3. This factor can be extracted from the velocity coefficient in the form $e^{-E/RT}$, leaving thus a factor independent of temperature which is still much less than 10^{11}. It is therefore clear that configurational effects are very important in determining radical-molecule reactivity too.

Polymer radicals do not always add to monomer. Occasionally they abstract a hydrogen atom, thus:

$$R{-} + CH_2{=}CHX \rightarrow RH + \dot{C}H_2{=}CX.$$

Once again radical reactivity is not destroyed, but naturally the continuity of the polymer chain is necessarily interrupted if the reaction goes in this fashion. This kind of dehydrogenation reaction has a serious effect in limiting the size of the polymer that can be synthesized. Its probability relative to that of polymer growth can be estimated by making simultaneous measurements of the number of monomer units in the polymer and the number of monomer units polymerized for each radical initially produced. For example, with styrene at 25° C the relative probability of transfer to growth is 10^{-3} [5]. If the radical so produced is not reactive, as occurs with allyl compounds,

TABLE I

Monomer	*Interaction coefficient for polymer radicals (litres moles^{-1} seconds^{-1})*
$CH_2{=}CH.COOC_4H_9$ ..	$1{\cdot}8 \times 10^4$
$CH_2{=}CH.C_6H_5$	$7{\cdot}9 \times 10^6$
$CH_2{=}C(CH_3)COOCH_3$	$2{\cdot}7 \times 10^7$
$CH_2{=}CHO.COCH_3$ ..	$3{\cdot}9 \times 10^8$
Oxidation reaction	*Interaction coefficient for RO_2 radicals*
Cyclohexene	$0{\cdot}95 \times 10^6$
1-Methyl-cyclohexene ..	$0{\cdot}50 \times 10^6$
Dihydromyrcene	$0{\cdot}65 \times 10^6$
Ethyl linoleate	$0{\cdot}50 \times 10^6$

TABLE II

Monomer	*Polymer radical monomer reaction coefficient at 25° C*	*Energy needed for radical growth (in kilocalories)*	*Collision factor when energy has been supplied*
$CH_2=CH.COOC_4H_9$	20	6·0	$5{\cdot}1 \times 10^5$
$CH_2=CH.C_6H_5$	40	6·0	$9{\cdot}0 \times 10^5$
$CH_2=C(CH_3)COOCH_3$	200	5·0	$9{\cdot}5 \times 10^5$
$CH_2=CH.O.COCH_3$	800	4·4	$1{\cdot}8 \times 10^6$

($CH_2 = CH - CHX$), molecular growth will also stop at the transfer stage. The degree of polymerization is then very seriously limited, and high polymers cannot be prepared.

When solvents are added to the system they may act as inert diluents, and any variation in rate of formation and molecular weight of the polymer is wholly due to mass-action effects. More often, however, transfer occurs by the removal of hydrogen (or perhaps halogen), the radical so formed being capable of reacting with the monomer so rapidly that no other fate befalls it. Competitive factors at once operate again. A polymer radical has a chance of either adding on another unit, or of reacting with the solvent, in which case the growth of that particular polymer radical is stopped. The quantitative measurement of the effect of solvent concentration on molecular weight gives this information, hence knowledge of the rate of polymer radical growth makes it possible to calculate the absolute rate of the transfer process. It is difficult to write down the chemistry of the process, but a fair presumption to make is that the hydrogen (in a hydrocarbon) which is most weakly bound to the carbon atom will be removed. Thus we find that the styryl radical attacks these aromatic hydrocarbons in the following order:

$$\underset{\text{isopropyl benzene}}{C_6H_5\overset{*}{C}H(CH_3)_2} > \underset{\text{ethyl benzene}}{C_6H_5\overset{*}{C}H_2CH_3} > \underset{\text{toluene}}{C_6H_5\overset{*}{C}H_3} > \underset{\text{benzene}}{C_6H_6},$$

the hydrogen atoms marked with a star being those removed. The radicals so far considered will, however, be more reactive in the opposite sense to the series for ease of transfer. It may happen that some molecules, e.g. vinyl acetate

$$(CH_2=CH.OCOCH_3),$$

are not particularly reactive towards radicals of this kind, and therefore some are lost by side reactions. In such cases the transfer agents begin to act as retarders of polymerization.

These studies have been successfully extended to co-polymerization of two monomers A and B in which the monomer units are built into the same macromolecule. By fixing A and studying the composition of the co-polymer formed with a variety of B monomers it is possible to evaluate precisely the reactivity of, say, a styryl radical to a whole variety of monomers. This again provides data of a reliable kind on the relationship between reactivity and molecular structure [7]. Similarly, by the study of the rate of production of co-polymer it is also possible to study the reactions between dissimilar polymer radicals. Just as interactions between like radicals are specific, so are the reactions between dissimilar radicals.

To conclude in a few words, the absolute determination of the velocity coefficients in a simple polymer reaction has led to the development of a quantitative radical chemistry the extent of which is practically unlimited. The compilation of data of this kind will provide the facts required to evolve more precise theories of organic reactions and to regulate the development of such theories.

REFERENCES

[1] Briers, F., Chapman, D. L., and Walter, E. *J. Chem. Soc.*, 562, 1926.
[2] Burnett, G. M., and Melville, H. W. *Proc. Roy. Soc. A*, 189, 456, 1947.
[3] Melville, H. W. *Third Symposium on Flame and Combustion.* University of Wisconsin. 1940.
[4] Bamford, C. H., and Dewar, M. J. S. *Proc. Roy. Soc., A*, 192, 309, 1948.
[5] Valentine, L., and Melville, H. W. *Trans. Faraday Soc.* (in press).
[6] Gregg, R. A., and Mayo, S. R. *Discussion of the Faraday Society on the Labile Molecule*, p. 328, 1947.
[7] Mayo, S. R., Lewis, F. M., and Walling, C. *Ibid.*, p. 285, 1947.
[8] Valentine, L., and Melville, H. W. *Proc. Roy. Soc.* (in press).

Book reviews

GAS SEPARATION

The Separation of Gases, *by M. Ruhemann. Pp. xii + 307. Clarendon Press, Oxford. Second edition,* 1949. 30*s. net.*

Most gases occur naturally as a component of complicated mixtures; the primary gaseous products of industrial processes contain a number of chemical species in diverse concentrations. Before they can be used it is generally necessary to alter their relative concentrations, or, in some cases, to separate the pure species.

The scientific basis of gas separation, or of altering the relative concentrations of the different species in a mixture, is to be found in the conditions of thermodynamical equilibrium developed by Willard Gibbs. That a system be in thermodynamical equilibrium with regard to a particular component requires that its partial or chemical potential be the same in each phase of the system. This condition implies a difference of concentration in the phases: a component tends to pass from a phase in which its partial potential is greater to a phase in which its partial potential is smaller.

This book gives an account of these thermodynamical principles, and of the way in which they have been applied to develop processes of gas separation. The main industrial processes depend primarily on liquefaction at low temperatures. The theory and practice of these processes are reviewed. The author then deals with the separation of air—including the production of the rare gases—and the production of hydrogen and hydrocarbons.

A. R. MILLER

A VIEW OF SCIENCE

The Freedom of Necessity, *by J. D. Bernal. Pp. xi + 437. Routledge and Kegan Paul Limited, London.* 1949. 18*s. net.*

The decay into which science fell in the second and third decades of the nineteenth century was largely a result of the reaction of the wealthy and powerful against its atheistical and Jacobin association: so Professor Bernal says. One could scarcely choose two decades more splendid for their record of scientific discovery. They saw the origin of three great modern sciences—biochemistry, histochemistry, and cytology—and the opening out of a whole new realm of organic chemistry with the discovery of benzene. Even if it could be shown that any two particular decades were periods of decay in science, we have no means of testing the truth of a dogmatic assertion that the decay was due to reactions of wealthy and powerful persons.

This is what Professor Bernal wrote about chromosomes in 1935 and reprints in the present book: 'The discovery of the mechanism of inheritance through the chromosome-theory (originally put forward by Mendel and now actually verifiable by microscopical observation) provides the material mode of transformation by which living animals develop and reproduce.' He can print this true statement (a heresy in the U.S.S.R. today) simply because he happens to live in a country where there is still freedom in science. His remark that there is no branch of human activity more dependent than science on the maintenance of liberty is confusing and deceptive to the last degree: it is contrary to the whole emphasis of his propaganda for the central direction of science.

JOHN R. BAKER

THE POTATO

The History and Social Influence of the Potato, *by Redcliffe N. Salaman, with a chapter on industrial uses by W. G. Burton. Pp. xxiv + 685, with a frontispiece, 32 plates, and 25 figures in text. University Press, Cambridge.* 1949. 50*s. net.*

This is a most unusual book. The author, whose work *Potato Varieties* (1926) is a classic, and who for more than forty years has studied the genetics and diseases of potatoes, attempts to answer such questions as what was the country of origin of the cultivated potato, what manner of people first made use of it, whence, when, and how did it first get to Europe, and how has it come about that in certain countries it replaced cereals as the main food plant, and with what result.

Evidence from prehistoric pottery suggests that long before the time of the Incas the indigenous tribes of the Andean uplands made use of tuber-bearing species of *Solanum*, among which a tetraploid hybrid, the ancestor of our potato, was the most important. Used by the Spaniards as a cheap, easily-raised food for their slaves in the silver mines, it was brought to Europe before 1570 and first grown at Seville. As a curiosity and luxury food it spread in western Europe, but was only slowly adopted as a popular article of diet. Recognizing the conservatism of peoples in the matter of food, Salaman believes that radical changes in diet are brought about only when factors, economic and political, compel a change, however suitable the soil and climate may be to the new crop. This thesis he develops for several countries, chiefly Britain and Ireland. The book is a mine of information, made readily accessible by a full index (40 pages), and a bibliography of some 800 references.

T. G. B. OSBORN

HETEROPOLAR AND OTHER BONDS

Molecules and Crystals in Inorganic Chemistry, *by A. E. van Arkel. Pp. ix + 234. Butterworth's Scientific Publications Limited, London.* 1949. *Translated by J. C. Swallow.* 17*s.* 6d. *net.*

Professor van Arkel's book has had a great success in the universities of the Netherlands, and the present translation is based on the third Dutch edition now in preparation. The author believes that a thorough grasp of the implications of the heteropolar bond provides a wide insight into inorganic chemistry as a whole. In the earlier chapters he discusses how the theory of the electrostatic bond can explain a number of phenomena in inorganic chemistry. However, he stresses the limitation of this treatment, and thereby introduces the reader to other chemical bonds which are considered in the later sections of the volume. The book is intended for students in their first year of science or medicine, but it is doubtful whether such students will have an adequate knowledge of general chemistry to derive real benefit from this book. It will, however, prove most interesting and stimulating to science students at a more advanced stage of their studies. There is no doubt that the writer is at times somewhat daring in his theoretical speculations, but this adds to the value of the text. Dr J. C. Swallow has carried out the task of translation in an exact and graceful manner. Chemists owe him a debt of gratitude for making available a scholarly and attractive exposition of a subject which is of lively interest to most chemists.

W. WARDLAW

SURFACE CHEMISTRY

Surface Chemistry: papers presented for a discussion of the *Société de Chimie Physique* and the Faraday Society, October 1947. *Pp.* 344. *Butterworth's Scientific Publications, London.* 1949. 25*s. net.*

This volume presents, in English and French, 42 papers contributed to the meeting held in honour of the veteran Henri Devaux, who contributes the first paper, describing ingenious experiments on the influence of moisture in the air on the area of films of salts and sugar on mercury. It includes papers on most branches of surface chemistry; a masterly concise summary by Guggenheim of theorems on surface thermodynamics; several others on phase changes and equilibria in surfaces; and a method of separating haemoglobin and catalase by frothing. Several papers from Cambridge attempt an attack on the complex problem of interpreting the biological action of various substances, particularly soaps and similar compounds, in terms of their surface activity. There are a number of papers on monolayers of fatty substances and proteins, and on their interaction with soluble substances; two papers on the distribution of ions near surfaces and ionic micelles; and some on technique. As usual in discussions, some of the papers describe work already published, but the volume is of great value, and indispensable to serious students of surface chemistry. It should also be studied by biologists interested in physical chemistry.

N. K. ADAM

PLANTS AND INORGANIC FOOD

Inorganic Nutrition of Plants, *by D. R. Hoagland. Pp.* 226, *with* 28 *plates and* 44 *text figures. Chronica Botanica Company, Waltham, Mass., U.S.A., and Wm. Dawson and Sons, Limited, London.* 1948. $4.50 *net.*

This book contains the Prather Lectures given at Harvard and first published during 1944, when they were not obtainable in Europe. It is valuable to have them reprinted, as they contain a good general survey of the work done by Professor Hoagland and his associates in California, and of other related researches in the field of mineral plant nutrition.

The virtues of this book lie in the breadth of outlook that has characterized its author's work. He has made notable contributions to the study of soil colloids and soil solutions, with special interest in the quantitative aspects of potassium absorption and movement. He was a leader in the realization of the significance of the accumulation of ions in plant cells, and in the demonstration of the dependence of salt absorption upon the energy relations of the cells. He has added greatly to our knowledge of the relations between ion-intake and cell-metabolism, and, not least, he has been fertile in the development of improved methods. He tells of these things in this book in a simple and attractive style.

W. H. PEARSALL

INDUSTRIAL CHEMICAL RESEARCH

The Practice of Research in the Chemical Industries, *by R. H. Griffith. Pp.* 184. *Oxford University Press, London.* 1949. 12*s.* 6*d. net.*

Although the author disowns any claim to novelty, he has nevertheless successfully collected a variety of opinions, drawn from scattered sources, which he discusses in such a way as to present a connected and readable account of the aims and methods of industrial chemical research.

The sections on the recruitment, training, and welfare of staff, though familiar ground to the manager of a research department, are a timely reminder to the research worker that the efficient management of industrial research has other aspects than the purely scientific.

The place, in a work of this kind, of some of the more detailed chapters, such as those on laboratory design and on indexing systems, is perhaps questionable, and, in a field where local requirements are so diverse, broad generalizations can be misleading: it is only fair to add that the author himself obviously realizes this fact.

Taken as a whole, the book is one which is very well worth the attention of all concerned either with the carrying out of industrial chemical research or with the utilization of its results. For the student also it should provide a welcome introduction to the special problems which arise from the application of research to industry.

L. W. CODD

X-RAY DIFFRACTION

The Optical Principles of the Diffraction of X-rays, *by R. W. James. Pp. xv* + 623, *with* 224 *half-tone and line illustrations. G. Bell and Sons Limited, London.* 1948. 80*s. net.*

It is not far short of twenty years since the Braggs and their collaborators first discussed the preparation of a series of volumes on 'The Crystalline State.' Vol. I, a general survey by W. L. (now Sir Lawrence) Bragg, appeared in 1933, but so many preoccupations, especially the war, have since intervened that it is only now that we see the next development of the plan. In the meantime, inevitably, its early outlines have been so overspread by the advance of discovery that the present vol. II covers no more than a part of the vol. II originally proposed, and even so is longer than the author anticipated. It is certainly too long and detailed to do justice to in a short notice of this kind, and beyond listing the principal headings (the geometrical theory of diffraction by space-lattices; the intensity of reflection of X-rays by crystals; the atomic scattering factor; the anomalous scattering and dispersion of X-rays; the influence of temperature on the diffraction of X-rays by crystals; experimental tests of the intensity formulae; the use of Fourier series in crystal analysis; Laue's development of the dynamical theory; the scattering of X-rays by gases, liquids, and amorphous solids; diffraction by small crystals) we can only say that Professor James, a former member of the Bragg school at Manchester, has done an excellent piece of work and given us a notable addition to the literature of structure analysis. On looking through it, the thought was bound to occur to the reviewer that Sir William Bragg would have been proud to share again with his son the editorship which inspired vol. I.

W. T. ASTBURY

STATISTICS IN GENETICS

Biometrical Genetics, *by K. Mather. Pp. ix* + 162, *with several line diagrams. Methuen and Company Limited, London.* 1949. 18*s. net.*

The classical theory of genetics has largely dealt with cases of discontinuous variation, such as the distinction between black, yellow, and white cats. It has long been known that continuously graded variation, such as that of height in man, is also inherited in a Mendelian manner, being due to the combined effect of several genes, each by itself having only a small effect. This book deals with the recently developed methods of analysing continuous variation. Although no single gene can be studied on its own, yet by suitable statistical methods one can show the segregation, dominance, and linkage of genes. These

properties are important in breeding for a continuously graded character.

The book is very lucidly written, and all formulae necessary for the analysis are carefully set out. The formulae will be strictly accurate only within certain limitations, notably that the effects of the separate genes should be exactly additive. This is unlikely in practice, but Professor Mather recognizes these limitations, and shows how errors from ignoring them can be minimized by using suitable scales of measurement.

The book has a complete set of references for further study, and is well indexed. C. A. B. SMITH

COLOURS

Colours and how we see them, *by H. Hartridge. Pp.* 158. *G. Bell and Sons Limited, London.* 1949. 15*s. net.*

In the winter of 1946–7 Professor Hartridge gave the Christmas lectures at the Royal Institution, and now presents them in the form of a book. In the first four chapters he discusses the properties of the spectrum, how colours are produced, colours and their uses, how colours are seen, and in the last two chapters describes some fascinating experiments and paradoxes with colour. The book is extremely lucid and readable, and is clearly intended for the general reader, only the most elementary scientific knowledge being assumed. The author has a way of explaining the numerous demonstrations given at the lectures so clearly that the reader who was unlucky enough not to have seen them may very readily imagine the effect. Moreover, enough information is given for him easily to repeat the experiments for himself. There can have been few books on this subject in which so many elegant demonstrations are collected.

In chapter IV Professor Hartridge briefly summarizes the anatomy and physiology of the eye, including the mechanisms of accommodation and convergence. Various theories of colour vision are mentioned, starting with that of Thomas Young. A simple account, based on Young's theory, is presented of a possible mechanism of colour vision, though it is admitted that the problem is complex and much remains to be worked out.

The book is illustrated by four half-tone plates, twelve plates in colour, and a large number of line diagrams in the text. It is a pity that in a book on this topic the colour plates are not of the highest possible quality, being printed on rather absorbent paper, while some apparently suffer from imperfect registration of the three colours.

J. M. M. PINKERTON

CHEMISTRY AND ANCIENT CHINESE ARTS

The Chemical Arts of Old China, *by Li Ch'iao-p'ing, with a foreword by Tenney L. Davis. Pp. xii* + 215. *Journal of Chemical Education, Easton, Pennsylvania.* 1948. *n.p.*

Prof. T. L. Davis's last letter to the present reviewer, written shortly before his death in January 1949, ends with the words 'the history of science is the essence of humanism.' In the light of this thesis, his ardent and invaluable services in the publication of the above book are readily understandable. Authoritative works dealing with the evolution of chemistry and applied chemistry in the Orient are extremely rare—at least in the English language—and this book by Prof. Li, of the National North-Eastern University, Mukden, is therefore of peculiar value not only to chemists but to everyone interested in the arts and crafts, the economics, and the general culture of the Far East.

A short chapter on Chinese alchemy is followed by a historical survey of metals, salt, ceramic industries, lacquer, gunpowder, dyes, oils, incense, sugar, paper, alcoholic beverages, and other related subjects. In each of his fifteen chapters the author raises the curtain for a tantalizing moment upon a vast field which the reader longs to study in more detail. Among the outstanding features of a most attractively produced volume are the delicately executed line illustrations, reminiscent of the familiar willow pattern of Nanking china: the processes of making Chinese ink, for example, are shown in a series of ten charming drawings of the kind. In view of the nature of the book, an index would be of much help. An improved documentation is equally desirable: thus, in a discussion of some of Chikashige's analyses of ancient bronze objects there is no reference to this author's book on *Alchemy and Other Chemical Achievements of the Ancient Orient* (Tokyo, 1936), containing so much cognate information. But the main criticism must be that this truly fascinating book is all too short.

JOHN READ

ENGLISH FARMING

Both Sides of the Road, *by Sidney Rogerson. Illustrated by Charles Tunnicliffe. Pp.* 183, *with* 107 *black and white and* 23 *coloured plates. Collins, London.* 1949. 21*s. net.*

This book has been written by Sidney Rogerson and illustrated by Charles Tunnicliffe 'to interest those of all ages who love the country and wish to know more about the farming scene,' and it is the English farming scene which is described. First we are taken from east to west by road, and from south to north by train to give us a view of the country which is to be farmed. Then the author settles down to tell us about farming, and the story flows so freely from his pen that technical descriptions are delightful to read. His description of a poor meadow is worth quoting: 'In winter the poor meadow or pasture stands revealed as a place of short grass pimpled with warts which are grass-clad molehills or ant-heaps.... Brambles fling wild tentacles over the rioting hedgerows and sullen nettles flourish in the ditches. The sward will bloom first with tall daisies and rank buttercups, and later with the grey spikes and purple brush of the thistle and the tough yellow columns of ragwort. Ragwort is a sure symbol of a ragged meadow.... The plants which will not flourish in such a sward are the succulent and nourishing grasses which are the justification of permanent grassland.' The author gives us a very full account of the basic facts of English farming, and Charles Tunnicliffe's illustrations make long descriptions in the text unnecessary. From the illustrations we can learn at once to recognize the different breeds of cows, sheep, and pigs, and the crops growing in the fields.

Author and illustrator have combined to produce a beautiful volume—the most readable book on farming which we have seen. R. E. SLADE

'SUDBOROUGH AND JAMES'

Practical Organic Chemistry, *by J. J. Sudborough and T. Campbell James. Blackie and Son Limited, London.* 1949. *Pp.* 450. 15*s. net.*

'Sudborough and James' has been for many years a highly valued textbook of practical organic chemistry. It was first issued in 1909 and was last revised in 1924. The publication of a new edition is therefore an event which

will be welcomed both by teachers and by undergraduates. To meet the changes in organic chemistry which have taken place during the last twenty-five years the book has been extensively revised, the good features of arrangement of the earlier editions being retained. In its present form it admirably suits the needs of students up to their final honours year. In addition to the well-tried old favourites, examples of more modern techniques are now to be found: for instance, chromatography, micro-analysis, chloromethylation, and the Diels-Alder reaction. The major portion of the volume consists of a systematically arranged series of preparations, but it contains also sections on quantitative methods of analysis, exercises in the determination of reaction velocities, and an outline of qualitative organic analysis. Misprints are few, although the names of Liebig, Crafts, Cannizzaro and Knoevenagel all occur incorrectly spelled. It would have been better to use the accepted *d-* or *l-* nomenclature for sugars, and more frequent references to 'Organic Syntheses' and fewer to the very early literature would have been advantageous. These are relatively minor points, however, and do not detract from the reviewer's opinion that this is a book which can be strongly recommended.

E. L. HIRST

INSECTICIDES

The Chemistry and Uses of Insecticides, *by E. R. de Ong. Pp.* 345, *with half-tones and line diagrams. Reinhold Publishing Corporation, New York; Chapman and Hall, London.* 1948. 36*s. net.*

The nature of this book can perhaps be best indicated by describing it as technological rather than scientific. It is an exhaustive survey of facts and practical details, but comparatively little space is devoted to theoretical or speculative discussion, e.g. to modes of biological action, or to relationships between molecular structure and toxicity.

Despite the publisher's claim on the wrapper that Mr de Ong's treatment is highly systematic, this absence of theoretical background has led to a far from systematic sequence of treatment. Indeed, the title itself is puzzling in this respect, for the author deals with fungicides quite as liberally as with insecticides. No attempt is made to treat these two different classes of plant-protective materials in separate sections; thus, a chapter on arsenic compounds as insecticides is abruptly followed by a chapter on the fungicidal copper compounds. Sequence of treatment seems to have been decided purely upon the dates of discovery or development of these various agricultural chemicals.

Nevertheless, the total amount of information that has been assembled is impressive. The documentation is lavish; the references given at the end of each chapter usually number more than 150. The author has wisely resisted topical temptations (prevalent in America at the time he was preparing this book) to devote an excessive attention to modern synthetic insecticides. These he has dealt with in realistic perspective. In so far as any book can remain for long an adequate reference work for this wide and fast-changing subject, Mr de Ong's survey will be a useful addition to many chemical and agricultural libraries. The high reference standard of this first edition will set him an arduous task for periodic revisions of the text.

D. P. HOPKINS

HUYGENS' COMPLETE WORKS

Œuvres complètes de Christiaan Huygens, volume XXII. *Published for the Société hollandaise des Sciences à Haarlem by Martinus Nijhoff, The Hague.*

As the whole of this edition of Huygens' works, begun in 1888, is now nearly completed, it is appropriate to draw the attention of the scientific public to this truly monumental edition.

Volume XXII deals mainly with some miscellaneous correspondence, biography, Huygens' will, and the catalogue of his library.

There exist early editions of a number of Huygens' works and also of parts of his correspondence, but these editions have long been out of print and today are very rare. They are moreover not complete, as none of the editors troubled to examine carefully all the manuscripts which Huygens bequeathed to the Leiden University Library.

The present edition is particularly important because it contains, besides the printed works (nearly all in Latin, with French translations), innumerable pages of the manuscripts, with a great number of Huygens' drawings and sketches, together with his entire correspondence, carried out with almost all the scientists of his time. Among the correspondence are many letters of a purely personal nature, so that one sees not only an excellent survey of the scientific life of the seventeenth century but also of the private life of an aristocratic Dutch family.

All the chapters are preceded by prefaces, often very elaborate, and all the texts are explained with the help of a large number of footnotes. The whole text is very fully indexed.

Many scientists who have been members of the editorial committee have contributed to the prefaces and footnotes. It is not possible to name them all, but four of them, who did by far the greatest part of the work, should be mentioned here: D. Bierens de Haan (1822–95), J. Bosscha (1831–1911), D. J. Korteweg (1848–1941), and J. A. Vollgraff.

C. A. CROMMELIN

CANADIAN CHEMISTRY

A History of Chemistry in Canada, *compiled by C. J. S. Warrington and R. V. V. Nicholls, with a foreword by T. W. Smith. Pp.* x + 502, *with* 13 *plates. Sir Isaac Pitman and Sons (Canada) Ltd., Toronto.* 1949. $4.50.

Published under the auspices of the Chemical Institute of Canada with the help of numerous specialists, this substantial work deals authoritatively with the historical development in Canada of various fields of chemistry, treated largely from the industrial point of view. The account starts with metals, and takes in such important subjects as fertilizers, mineral products, chemicals from coal, petroleum and its derivatives, products of the electric furnace, of electrolysis, of wood, of agriculture and of the sea, medicinal and fine chemicals, explosives, oils, fats, and waxes, and so forth. In each section the information is brought up to date and many statistics are quoted; thus a realistic picture is presented of Canada's great natural resources and their development as viewed by the chemist. Still further chapters deal with chemistry and public services, and with chemical teaching and research in Canadian universities and other institutions. Much detail is included of the men who have made Canadian chemistry, in both industrial and academic circles. The book is well printed, with numerous illustrations in the form of photographs, maps, portraits, and sketches.

JOHN READ

Some books received

Chemical Society Annual Reports. *Vol. XLV*, 1948. *Pp.* 379. *Chemical Society, London.* 1949. 25*s. net.*

Multi-Enzyme Systems, *by Malcolm Dixon. Pp.* 100, *with line diagrams. Cambridge University Press, London.* 1949. 7*s.* 6*d. net.*

Introduction to Radiochemistry, *by Gerhart Friedlander and Joseph W. Kennedy. Pp.* 412, *with various line and half-tone illustrations. John Wiley and Sons, New York; Chapman and Hall, London.* 1949. 40*s. net.*

Electronic Interpretations of Organic Chemistry, *by A. Edward Remick. Pp.* 600, *with various line illustrations. John Wiley and Sons, New York; Chapman and Hall, London.* 1949. 48*s. net.*

Outlines of Biochemistry, *by Ross Aiken Gortner. Third edition. Pp.* 1078, *with many line drawings. John Wiley and Sons, New York; Chapman and Hall, London.* 1949. 60*s. net.*

Quantitative Organic Analysis via Functional Groups, *by Sidney Siggia. Pp.* 152. *John Wiley and Sons, New York; Chapman and Hall, London.* 1949. 24*s. net.*

How Chemistry Works, *by Arthur J. Birch. Pp.* 218, *with various line diagrams. Sigma Books, London.* 1950. 8*s.* 6*d. net.*

Cathode Ray Tube Traces, *by Hilary Moss. Pp.* 66, *with numerous line diagrams. Electronic Engineering, London.* 1949. 10*s.* 6*d. net.*

Cosmic Ray Physics, *by D. J. K. Montgomery. Pp.* 370, *with numerous line diagrams. Princeton University Press, U.S.A.; Oxford University Press, London.* 1949. 40*s. net.*

Artificial Radioactivity, *by P. B. Moon. Pp.* 102, *with various line drawings. Cambridge University Press, London.* 1949. 12*s.* 6*d. net.*

Magnetism, *by David Schoenberg. Pp.* 216, *with several line diagrams and half-tone illustrations. Sigma Books, London.* 1949. 10*s.* 6*d. net.*

Extrapolation, Interpolation and Smoothing of Stationary Time Series, *by Norbert Wiener. Pp.* 160. *John Wiley and Sons, New York; Chapman and Hall, London.* 1949. 32*s. net.*

Recent Advances in Radio Receivers, *by L. A. Moxon. Pp.* 183, *with various line illustrations. Cambridge University Press, London.* 1949. 18*s. net.*

Engineering Structures. *Colston papers based on a symposium promoted by the Colston Research Society. Edited by A. G. Pugsley and D. R. Rexworthy. Pp.* 260, *with numerous half-tones and line diagrams. Butterworth's Scientific Publications, London.* 1950. 25*s. net* (21*s. to* Research *subscribers*).

Surface Tension and the Spreading of Liquids, *by R. S. Burdon. Pp.* 92, *with various half-tones and line diagrams. Cambridge University Press, London.* 1949. 12*s.* 6*d. net.*

Some Recent Researches in Solar Physics, *by F. Hoyle. Pp.* 134, *with various line diagrams. Cambridge University Press, London.* 1949. 12*s.* 6d. *net.*

Excited States of Nuclei, *by S. Devons. Pp.* 152, *with various line diagrams. Cambridge University Press, London.* 1949. 12*s.* 6d. *net.*

The Adsorption of Gases on Solids, *by A. R. Miller. Pp.* 133, *with numerous line diagrams. Cambridge University Press, London.* 1949. 12*s.* 6*d. net.*

Oscillations of the Earth's Atmosphere, *by M. V. Wilkes. Pp.* 74, *with various line diagrams. Cambridge University Press, London.* 1949. 12*s.* 6*d. net.*

Aviation Medicine, *by Kenneth G. Bergin. Pp.* 447, *with numerous half-tones and line illustrations. John Wright and Sons, Bristol; Simpkin Marshall* (1941), *London.* 1949. 35*s. net.*

The Theory of Inbreeding, *by Ronald A. Fisher. Pp.* 120. *Oliver and Boyd, Edinburgh.* 1949. 10*s.* 6*d. net.*

Soviet Genetics and World Science, *by Julian Huxley. Pp.* 245. *Chatto and Windus, London.* 1949. 8*s.* 6*d. net.*

Death of a Science in Russia, *by Conway Zirkle. Pp.* 319. *University of Pennsylvania Press, Philadelphia.* 1949. $3·75.

The Coming Age of Wood, *by Egon Glesinger. Pp.* 279, *with several illustrative charts. Martin Secker and Warburg, London.* 1950. 12*s.* 6*d. net.*

Alcohol, a Fuel for Internal Combustion Engines, *by S. J. W. Pleeth. Pp.* 259, *with various line diagrams. Chapman and Hall, London.* 1949. 28*s. net.*

Traité de Zoologie, *Vol. VI. Onychophores, Tardigrades, Arthropodes, Trilobitomorphes, Chélicérates. Published under the direction of Pierre-P. Grassé. Pp.* 979, *with numerous coloured plates, half-tones, and line drawings. Masson et Cie, Paris.* 1949.

Traité de Zoologie, *Vol. IX. Insectes: Paléontologie, Géonémie, Insectes Inférieurs, Coléoptères. Published under the direction of Pierre-P. Grassé. Pp.* 1117, *with numerous coloured plates, half-tones and line diagrams. Masson et Cie, Paris.* 1949.

The History of the Biochemical Society, 1911–1949, *by R. H. A. Plimmer. Pp.* 24, *with numerous half-tone plates. Cambridge University Press, London.* 1949. 2*s.* 6*d. net.*

Bergwerk- und Probierbuchlein. *From the sixteenth-century German texts, translated and edited by A. G. Sisco and C. S. Smith. Pp.* 196, *with numerous line drawings. American Institute of Mining and Metallurgical Engineers, New York.* 1949. $5 *net.*

The Personality of William Harvey, *by Geoffrey Keynes. Pp.* 48, *with eight portraits. Cambridge University Press, London.* 1949. 5*s. net.*

Crucibles: The Story of Chemistry, *by Bernard Jaffe. Third edition, revised and enlarged. Pp.* 480. *Hutchinson's Scientific and Technical Publications, London.* 1950. 18*s. net.*

Mathematics and the Imagination, *by James Newman. Pp.* 380, *with numerous line diagrams. G. Bell and Sons, London.* 1949. 15*s. net.*

The Infancy of Speech and the Speech of Infancy, *by Leopold Stein. Pp.* 209, *with several line drawings and half-tone illustrations. Methuen and Company, London.* 1949. 21*s. net.*

Snowdonia, the National Park of North Wales, *by F. J. North, Bruce Campbell and Richenda Scott. Pp.* 469, *with* 56 *colour plates,* 48 *black and white photographs, and* 6 *maps and* 26 *diagrams. Collins, London.* 1949. 21*s. net.*

Glass-to-metal Seals, *by J. H. Partridge. Pp.* 238, *with numerous half-tones and line diagrams. The Society of Glass Technology, Sheffield.* 1949. 35*s. net.*

The Power and Limits of Science, *by E. F. Caldin. Pp.* 196. *Chapman and Hall, London.* 1949. 12*s.* 6*d. net.*

Notes on contributors

SIR JOHN COCKCROFT,
C.B.E., M.A., Ph.D., Hon. LL.D. (Toronto), F.R.S.,

Was born at Todmorden, Yorkshire, in 1897 and was educated at Todmorden Secondary School, Manchester University, and St. John's College, Cambridge. After serving in the Royal Artillery in the first world war he studied electrical engineering at the Manchester College of Technology, and afterwards went to Cambridge to take the Mathematical Tripos in 1924. After working with Kapitza on the production of strong magnetic fields and low temperatures he collaborated with E. T. S. Walton on the disintegration of nuclei. From 1935 he took charge of the Royal Society Mond Laboratory at Cambridge and directed its research on low temperatures. He was university lecturer in Physics, a Fellow of St John's College, and in 1939 Jacksonian Professor of Natural Philosophy. During the war he worked on radar as chief superintendent of the Air Defence Research and Development Establishment. In 1940 he took part in early considerations of the feasibility of atomic bombs. In 1944 he accepted the directorship of the Montreal Laboratory of the National Research Council of Canada, and became Director of the Chalk River Laboratories. In 1946 he returned to England to become director of the Atomic Energy Research Establishment, Harwell.

C. A. CROMMELIN

Was born in 1878 and studied mathematics and physics at Leiden University, chiefly under H. A. Lorentz and H. Kamerlingh Onnes. He was subsequently assistant, conservator, and vice-director of the Kamerlingh Onnes cryogenic laboratory at Leiden; he also lectured on physics, and was director of the school for fine-mechanics, glass-blowing, and glass-grinding in the Kamerlingh Onnes laboratory, and of the National Museum for the History of Science. He is the author of many papers on physics and the history of physics.

GEORG KIRCHNER.

Born 1875; entered upon an administrative career in state mining concerns. From 1900 to 1944 in the service of the amber works, Königsberg, and Palmnicken, East Prussia (last owner: *Preussische Bergwerks-und-Hutten A.G.*, Berlin). He was manager of the concern dealing with the preparation of raw amber and its sale as a raw material in the world market. The first scientific classification and arrangement of all finds of amber fossils were in his hands.

H. J. J. WINTER,
M.Sc., Ph.D., A.Inst.P., F.R.Asiatic S.,

Was born in 1912 and was educated at the City School, Lincoln, University College, Nottingham, and University College, Exeter. He is a member of the History of Science Society and of the British Society for the History of Science. Lecturer in Education (Scientific Method and History of Science) in the University College of the South West, Exeter, he has published many papers on the history of science.

H. EPHRUSSI-TAYLOR,
M.A., Ph.D.

Born in the U.S.A. in 1918, and brought up in Washington, D.C. Was educated at Radcliffe College, University of California, and Columbia University, where she specialized in animal physiology and genetics. In 1945 held a fellowship at the New York Psychiatric Institute, working in biochemistry. In 1946 began working on *Pneumococcus* transformations with Dr O. T. Avery, at the hospital of the Rockefeller Institute for Medical Research, while holding a fellowship of the National Research Council. Continued work there for a second year, on the staff of the Institute. In France, married to Boris Ephrussi, professor of genetics at the Sorbonne, she continues to work in Paris as *Chargé de Recherche* of the *Centre National de la Recherche Scientifique*, attached to the *Institut de Génétique*. Interested primarily in problems of heredity, thus far her work has been centred upon heredity in bacteria.

JOHN HAMMOND,
C.B.E., M.A., D.Sc., F.R.S.,

Was born at Briston, Norfolk, in 1889, entered Downing College, Cambridge, in 1906, and studied natural sciences and then agriculture. A career of research in agricultural physiology at the Animal Nutrition Institute, School of Agriculture, Cambridge, was interrupted by the 1914 war, during which he served in the Norfolk Regiment in France and afterwards on the Staff. Returning after the war to Cambridge, he continued research work on problems of fertility, meat, and milk production. He visited many overseas countries to study or report on their animal industries. Became a Fellow of Downing College, Cambridge, in 1936, and Reader in Agricultural Physiology, University of Cambridge, in 1943. Served on the European Livestock Committee of UNRRA and is a member of the editorial board of the *Journal of Agricultural Science* and *British Journal of Nutrition*. His scientific publications include *Reproduction in the Cow* (1927), *Growth and Development of Mutton Qualities in the Sheep* (1932), *Farm Animals: their Breeding, Growth and Inheritance* (1940), and *The Artificial Insemination of Cattle* (1946).

ERNEST TILLOTSON,
M.Sc., F.G.S., F.R.A.S.,

Was born in 1904 and studied geology, mathematics, and physics at Leeds University. He has done research and published a number of papers on seismology and geophysics. He is honorary secretary of the British Association Seismological Committee, a member of the American Geophysical Union, and seismological correspondent to *Nature*.

H. W. MELVILLE,
Ph.D., D.Sc., F.R.S., F.R.I.C.,

Was born in Edinburgh in 1908. He first went to the Heriot-Watt College there, and then to the university to study physical chemistry. With the award of an 1851 Senior Studentship he went to work in the colloid science laboratory, Cambridge, and became a Fellow of Trinity College and subsequently assistant director of the laboratory. He was appointed to the chair of chemistry at Aberdeen University in 1940, but did not take up the appointment owing to his departure to the Ministry of Supply for a variety of duties during the war. In 1941 he was elected a Fellow of the Royal Society. After the war he went to Aberdeen and established the school of high polymer chemistry, with concurrent and continuing interest in the mechanism of chemical reactions. In 1948 he was appointed to the Mason Chair of chemistry in the University of Birmingham.

Made and printed in Great Britain at THE KYNOCH PRESS, *Witton, Birmingham, 6, for the publishers*
IMPERIAL CHEMICAL INDUSTRIES LIMITED, *London, S.W.1*